Rio Blanco
Oil Shale Project

AN EVALUATION OF THE SOILS OF TRACT C-a AND ADJACENT AREAS

by
Colorado School of Mines Research Institute
P.O. Box 112
Golden, Colorado 80401

Project J51105
December 8, 1976

Gulf Oil Corporation
and
Standard Oil Company (Indiana)
`725 East Hampden Avenue, Denver, Colorado 80231

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COLORADO SCHOOL OF MINES RESEARCH INSTITUTE

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Prepared for

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Project J51105

December 8, 1976

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INTRODUCTION AND OBJECTIVES

The extensive deposits of oil shale in the Green River Formation have been looked upon as a potential source of oil for many years. Recent problems in energy supplies have focused attention on commercial development of the oil shale. Prior to commercial development of this energy source, extensive environmental baseline studies are needed. An essential part of a baseline study concerns the soil.

Both the chemical and physical properties of the soil are important in determining what plant species will survive and how productive the surviving species will be. The quality of plant material is another important consideration. Some soils may contain certain chemical constituents which can be absorbed and accumulated by plants. When such plants are ingested by herbivores, sickness or death can result. Soils used in reclaiming mined areas should be free of toxicants and should be capable of supporting the quantity and the quality of vegetative material that existed prior to the disturbance.

The federal government has leased several tracts of land for possible oil shale development in the Piceance Creek Basin of the Green River Formation. The following soil study was conducted on oil shale Tract C-a and on adjacent areas that may be used in the mining process. Tract C-a is located approximately 30 miles northwest of Rifle, Colorado in the southern part of Rio Blanco County. This soil study is part of an extensive environmental study directed by the Rio Blanco Oil Shale Program (RBOSP).

The objectives of this soil program are as follows:

1. to determine the chemical and physical traits of the soils of Tract C-a and of adjacent areas prior to any significant disturbance by man,
2. to describe and to map the soils of Tract C-a,
3. to determine the location and the amount of soil (topsoil) material suitable for use as a top dressing on areas disturbed in the mining process.

In pursuance of these objectives, 352 soil samples were taken during the spring and summer of 1976. The soils were subjected to extensive laboratory analyses. Samples also were taken of the processed oil shale and analyzed in the same manner as the soil samples. Soil mapping and description also were carried out during the late spring and summer of 1976.

Appreciation is extended to Dr. Sterling Olsen, Soil Scientist and Research Leader, Agricultural Research Service, Fort Collins, Colorado for his technical assistance in the preparation of this report. Appreciation is also extended to Mr. Clayton Speers, Soil Conservation Service, Grand Junction, Colorado and to Mr. W. Pat Tripp, Soil Conservation Service, Meeker, Colorado for their assistance in the field description and classification of the soils of the study area.

SUMMARY AND CONCLUSIONS

The chemical and physical properties of the soils of Tract C-a and of adjacent areas are typical of semi-arid regions in the western United States. Saline and sodic materials were found in the study area, but these traits appeared to affect plant growth only when they were of relatively high magnitude and when they occurred within the first 50 cm of soil. The concentration of macro- and micronutrients were generally within the ranges expected. However, some sampling sites had unusually high concentrations of nitrate or molybdenum. Trace element concentrations were within the ranges considered normal for surface soils and nontoxic to plants and animals. Selenium was the only exception, and three sampling sites contained more plant-available selenium than is normally found in soils of semi-arid regions. The levels of background radioactivity were low and within the range considered nonsignificant to living organisms. Physical analyses pointed out that most of the soils of the study area were of coarse to medium texture and had the potential to retain sufficient water and nutrients for normal plant growth.

Many soil traits displayed an increase in concentration as depth increased. Salinity, pH, exchangeable sodium percentage, organic matter, and many plant nutrients increased significantly in concentration with increasing depth. Trace elements and physical properties were generally constant as depth increased.

In general, vegetation did not appear to significantly affect soil traits. However, greasewood was found to occur on saline, sodic, and strongly alkaline soils. Nitrate, sulfate, and selenium were also unusually

high where greasewood dominated. A limited investigation of soils under individual pinyon pine trees and in open areas suggested that pinyon pine significantly influences many soil traits.

Soil traits of Tract C-a alone and of 84 Mesa alone were very similar to those of the entire study area. However, soils found on 84 Mesa were higher in electrical conductivity and contained higher concentrations of most water-soluble macronutrients than the soils of the study area.

Nine soil series were found in the study area. These series were mapped and an individual profile within each series was described. A comparison of the chemical and physical properties demonstrated that these soil series had very similar characteristics, with the exception of the Torriorthent series. Soils of this series were saline, high in water-soluble macronutrients, and generally high in the concentration of trace elements.

The depth and location of topsoil suitable for use in reclamation was determined. Topsoil depth ranged from 0 to 150 cm. Rock was the most common limiting factor to topsoil depth. In some areas, the presence of sodic or saline material limited the depth of topsoil.

Processed oil shale was analyzed and evaluated for use as a subsurface medium for plant growth. This shale was found to be highly saline, sodic, and high in plant-available molybdenum. It appears that these traits will not significantly reduce seed germination and plant growth if at least 50 cm of suitable topsoil (as found on Tract C-a and on 84 Mesa) are applied to the processed shale surface.

METHODS

THE STUDY AREA

Intensive soil sampling was conducted on Tract C-a and an area to the northeast known as 84 Mesa (see Figure 1). Scattered samples were taken along Cathedral Bluffs and in areas south and east of Tract C-a.

This study area is characterized by northeast trending canyons and ridges. Valley floors are narrow, canyons are steep, the ridges are broad and flat to undulating. The elevation of Tract C-a ranges from 6,600 feet in Corral Gulch to 7,400 feet on the ridges near the southwest portion of the tract. The elevation of 84 Mesa is approximately 6,500 feet and the sampling areas on Cathedral Bluffs were slightly over 8,600 feet. Annual precipitation in the study area ranges from approximately 12 to 24 inches. Approximately 50 percent of the precipitation occurs as snow from December to April. Precipitation in late spring and fall is minimal. Summer is characterized by infrequent, but intense, convection storms. Big sagebrush and pinyon-juniper are principal plant communities of this area.

FIELD METHODS

Several criteria were used to determine the location of each soil sampling site. Many locations were chosen because they typified the soil series under study. Other sites were sampled because the soil supported a particular type of vegetation. Sampling sites were also located at potential monitoring sites. Some of these sites were located several miles from Tract C-a. These area may serve as a control to evaluate changes in baseline conditions. Other stations

were located in areas that may receive pollution from the proposed mining and processing activities. These areas may serve as a control to evaluate changes from baseline conditions. Finally, sampling on some areas was conducted to determine the depth of topsoil that could be removed and later used in reclamation. Sampling sites were flagged and assigned a number.

A backhoe was used to dig a trench approximately 5½ deep, 18 in. wide 5 ft long. Sampling pits were hand dug in areas not accessible to a backhoe. Prior to sampling, the pit wall was scraped to remove possible contamination from the bucket of the backhoe. Samples were carefully extracted to equally represent all portions of the sampling interval. However, in pits containing considerable rock, the sampling was confined to unconsolidated areas of the sampling interval. To a limited extent, roots and organic debris were removed from the sample. Each sample was placed in a cloth bag and immediately air-dried. The sampling area was described as to slope, aspect, dominant vegetation, and other pertinent factors. A color photograph was taken of the sampling pit. A tagged steel stake was driven in at the sampling location and another longer stake was placed near the road or in some other visible location. The sampling pit was then filled (with the surface material being placed back on the surface), packed, and seeded. Prior to leaving any given site, a sample of the dominant vegetation was taken. This sample was air-dried and retained for chemical analysis.

Sampling of depth intervals were of two types. Most samples were taken at the following specified depths: 0-10 cm, 10-50 cm, 50-100 cm, and 100-150 cm. Of the 352 samples collected, 312 were collected by specific depths. The second type of sampling was based on soil horizons. At a point that was considered representative of the soil series under study, a sample was taken of each soil horizon down to a depth of 150 cm. This type of sampling was conducted at 9 locations and 40 soil samples were collected in this manner.

Where sampling was done on the basis of soil horizon, a description was made of each soil horizon and other pertinent information about the soil series collected. Mr. Clayton Speers (Soil Conservation Service, Grand Junction, Colorado) and W. Pat Tripp (Soil Conservation Service, Meeker, Colorado) aided in the soil description and classification. These two individuals are largely responsible for the soil mapping and classification in this part of Colorado.

A preliminary soils map was made using recent aerial photographs and the soil map prepared by the Soil Conservation Service. This map was then refined on the basis of field reconnaissance and soil sampling.

LABORATORY METHODS

Sample Preparation

The air-dried samples were passed through a 9-mesh sieve (2 mm) and the screen undersize retained for analysis. Unincorporated organic matter (roots, leaves, twigs, etc.) were removed during sieving. Each

sample was then blended and split for chemical and for physical analyses. The material for chemical analysis was ground to a 150 mesh size.

Eight samples of processed oil shale were taken from a large sample supplied by the Rio Blanco Oil Shale Program. These samples were then treated in the same manner as the soil samples.

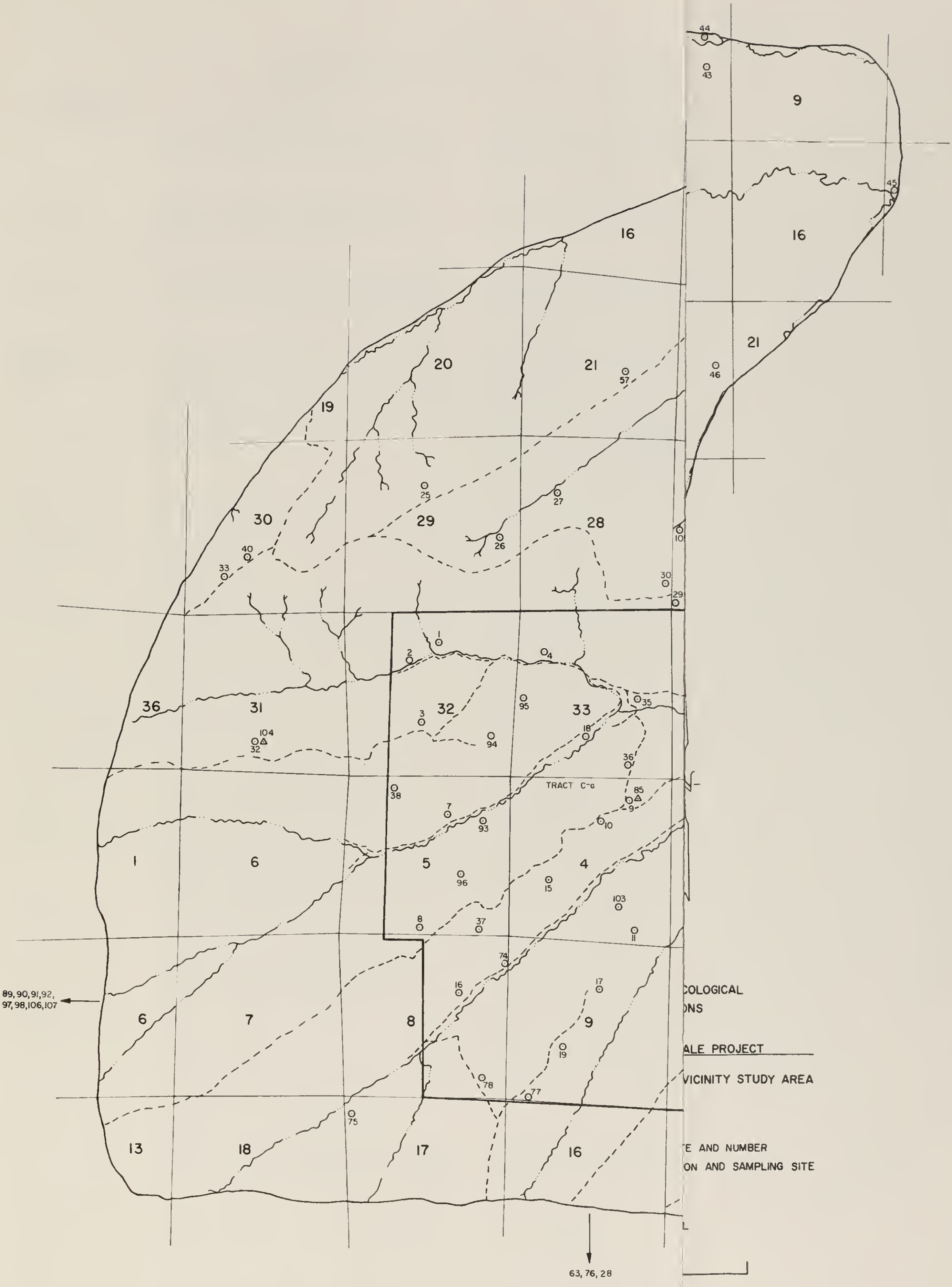
Chemical and Physical Analyses

Standard agronomic methods were used, as far as possible, in analyzing the samples. When possible, a plant available method was used to determine trace element concentrations. However, laboratory procedures for measuring the availability of some trace elements to plants have yet to be developed. In the absence of reliable methods, the total trace element concentration was determined.

A list of the laboratory methods employed and the reference from which the method was taken is found in Table 1.

STATISTICAL METHODS

When appropriate, standard statistical methods as described by Steel and Torrie (1960) were used to evaluate the data. The 5% level was used in determining the significance of statistical tests.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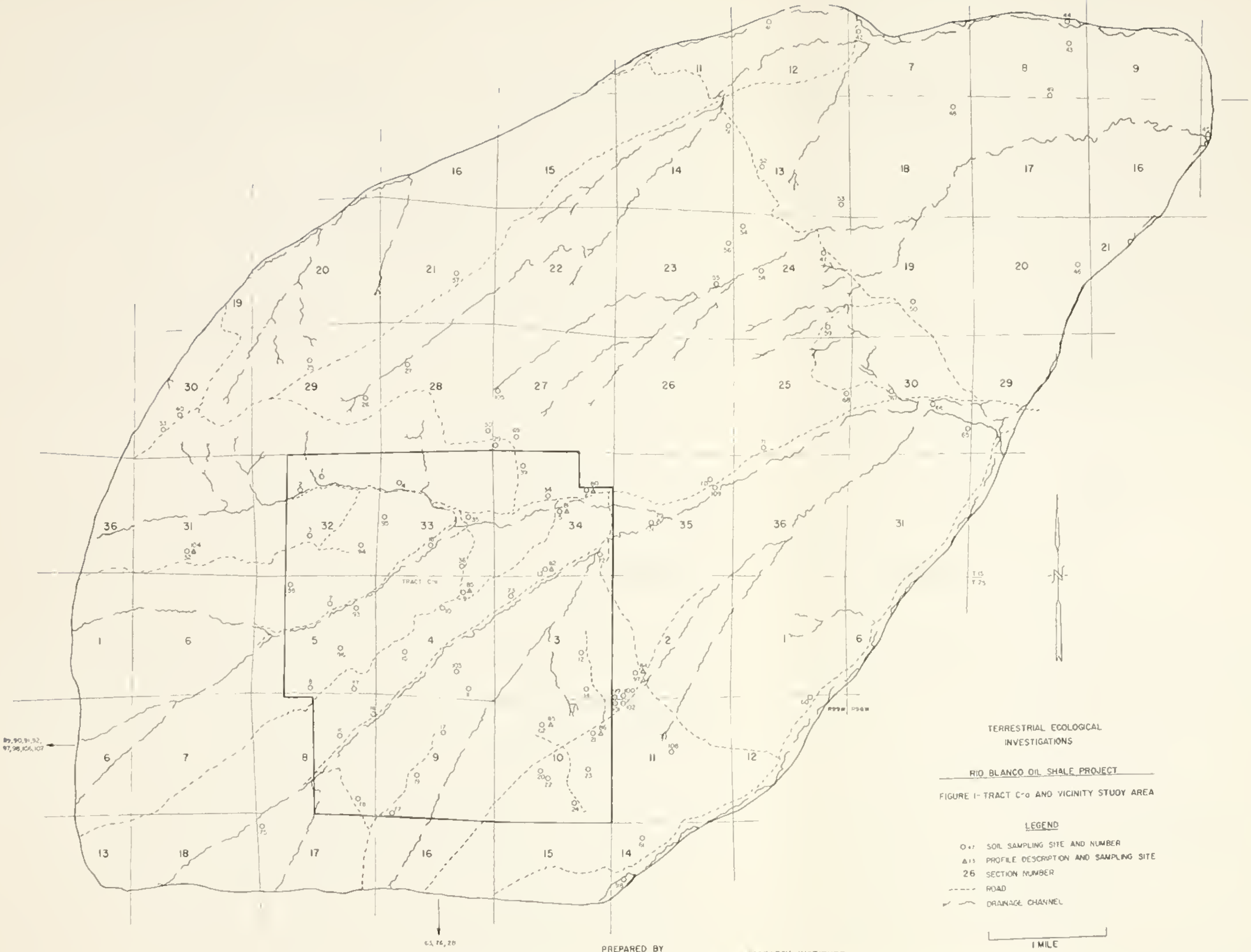

TERRESTRIAL ECOLOGICAL
INVESTIGATIONS

RIO BLANCO OIL SHALE PROJECT

FIGURE I- TRACT C-a AND VICINITY STUDY AREA

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TABLE 1

Chemical and Physical Analytical Methods for Soils

Analysis	Method	Reference	Detection Limit
pH	This is measured in a solution of 1 part soil to 2 parts deionized water.	American Society of Agronomy (ASA) Monograph No. 9, Methods of Soil Analysis, Method 60-3.4, p. 922-923.	0.1
pH($CaCl_2$)	pH is measured in a 0.01M $CaCl_2$ solution, 1 part soil to 5 parts solution.	ASA Agronomy Monograph No. 9, Method 60-3.5, p. 923.	0.1
Conductivity	Electrical conductivity is measured on water extracted from the sample.	American Society for Testing and Materials (ASTM), Publication STP 479, p. 288-290.	0.1 mmhos/cm
Cation-exchange capacity	The ability of soil particles to retain cations is measured.	ASA Agronomy Monograph No. 9, Method 57-3, p. 899-900.	0.1 MEQ/100 g
Iron	Diethylenetriamine penta-acetic acid (DTPA) is used to extract plant-available iron.	Follett, R.H., and W.L. Lindsay, 1971. Changes in DTPA extractable zinc, iron, manganese, and copper in soils following fertilization. Soil Sci. Soc. Am. Proc. 35: 600-602.	1.0 ppm
Copper	Same as above.	Same as above.	0.5 ppm
Manganese	Same as above.	Same as above.	1.0 ppm
Zinc	Same as above.	Same as above.	0.2 ppm
Fluoride	The sample is decomposed and total fluoride determined by the specific ion electrode.	ASA Monograph No. 9, Method 82-2, p. 1138-1139.	1.0 ppm
Chloride	Same as above.	Same as above.	1.0 ppm
Organic matter	Organic matter is oxidized by $K_2Cr_2O_7$.	ASA Monograph No. 9, Method 90-3, p. 1372-1376.	0.1%
Lime requirement	This is determined by a barium chloride-triethanolamine method.	ASA Monograph No. 9, Method 61-2.2, p. 928-929.	5.0%
Gypsum requirement	The sample is saturated with gypsum. The calcium and mannesium in solution are then measured.	Diagnosis and Improvement of Saline and Alkali Soils, U.S.D.A. Handbook No. 60, Method 22D, p. 104-105.	0.2 MEQ/100 g
Arsenic	Total arsenic is determined by a gaseous hydride method.	U.S. EPA Methods for Chemical Analysis, p. 9-10.	1.0 ppm
Cadmium	The sample is decomposed by mineral acids and total cadmium is read by atomic absorption.	Same as above, except p. 101.	0.5 ppm
Chromium	Same as above.	Same as above, except p. 105.	5.0 ppm
Cobalt	Same as above.	Same as above, except p. 107.	1.0 ppm
Mercury	Total mercury is determined by a manual cold vapor technique.	Same as above, except p. 118-126.	10 ppb
Phosphorus	Plant available phosphorus is determined by the $NaHCO_3$ soluble method.	ASA Agronomy Monograph No. 9, Method 73-4.4, p. 1044-1047.	1.0 ppm
Phosphorus	Total phosphorus is measured after the soil has been treated with perchloric acid.	ASA Monograph No. 9, Method 73-2, p. 1036-1037.	1.0 ppm
Sodium	Ammonium acetate is used to extract the sodium, the sodium is then determined by atomic adsorption spectrophotometry.	ASA Agronomy Monograph No. 9, Methods 71-3.2, 72-3.2, p. 1026-1027, p. 1033-1034.	0.01 MEQ/100 g

TABLE 1 -- continued

Analysis	Method	Reference	Detection Limit
Lead	Same as above.	Swaine, D.J., and R.L. Mitchell, 1960. Trace-element distribution soil profiles. Jour. Soil Sci. 11: 347-367.	0.5 ppm
Nickel	Same as above.	Same as above.	0.2 ppm
Potassium	Same as above.	ASA Monograph No. 9, Methods 71-3.2, 71-4, p. 1026-1027, p. 1027-1030.	5.0 ppm
Molybdenum	Plant-available molybdenum is determined by an anion risen extract.	Soil Science, Vol. 100, No. 8, 1965, p. 309-318, except that a modified procedure developed by Dr. S. R. Olsen is used to prepare the analysis solution.	0.1 ppm
Sodium	The sodium is extracted by water (1 part soil to 2 parts water) by atomic absorption spectrophotometry.	ASA Monograph No. 9, Method 62-3.3, p. 944-945.	0.01 MEQ/100 g
Potassium	Same as above.	Same as above.	0.4 ppm
Calcium	Same as above.	ASA Monograph No. 9, Method 62-3.2, p. 941-942.	0.4 ppm
Magnesium	Same as above.	Same as above.	0.4 ppm
Sulfate	Same as above.	ASA Agronomy Monograph No. 9, p. 1108-1110. APHA, AWWA, WPCF, Standard Methods for Examination of Water and Wastewater, 13th Edition, p. 334-335.	5.0 ppm
Boron	The soil sample is leached with water as above and the boron determined by spectrophotometic methods.	ASA Monograph No. 9, Method 62-3.6, p. 949-951.	0.1 ppm
Ammonium	A steam-distillation method is used to determine exchangeable ammonium.	ASA Monograph No. 9, Method 84-3, p. 1191-1206.	0.3 ppm
Nitrate	A chlorimetric phenoldisulfonic acid method is used.	ASA Monograph No. 9, Method 84-5, p. 1212-1219.	0.1 ppm
Vanadium	Total vanadium is determined by a chlorometric method (acid decomposition).	Anal. Chim. ACTA, 1964, Vol. 31, p. 147.	10 ppm
Antimony	Total antimony is determined by a potassium pyrosulfate fusion method.	U.S. EPA Methods for Chemical Analysis. p. 94.	1.0 ppm
Selenium	Plant-available selenium is determined on a water extract.	ASA Monograph No. 9, Method 80-3.2, p. 1119-1122.	10 ppb
Background radiation	Each sample is analyzed for the following: Uranium Equivalent Uranium Equivalent Thorium Potassium Radioactivity Radium	Adams, J.A.S. and P. Gasarani, 1970, Chapter 5.	1.0 ppm
Texture	The sample is dispersed in water and readings taken during a 24-hr period using a hydrometer.	ASA Monograph No. 9, Method 43-5, p. 562-566.	1.0%
Water-holding capacity	The sample is saturated with water, pressure is applied, and the sample weighed when equilibrium is attained.	ASA Monograph No. 9, Method 8-2.3, p. 134-137.	1.0%
Bulk density	A cylinder of known volume is pushed into the soil. The soil is extracted, dried, and weighed.	Hillel, D., 1971. Soil and Water, p. 10.	0.5 g/cm^3

RESULTS AND DISCUSSION

The results and discussion are divided into 6 major sections. Soil properties of the study area based on the 312 soil samples taken by specific depths are discussed in the first section. The next two sections consider separately the traits of Tract C-a and of 84 Mesa. A description of each soil series that occurs in the study area is presented in the fourth section. Most of this discussion is based on the 40 samples taken on the basis of soil horizon. The fifth section evaluates the soils for use as topsoil in reclamation efforts. The last section discusses the properties of spent shale and how these properties might influence plant growth when the spent shale serves as a subsoil.

SOIL PROPERTIES OF THE STUDY AREA

General Soil Properties ✓

The following discussion considers general soil properties of the entire study area (as shown in Figure 1). Mean, range, and standard deviation of each parameter are presented in Table 2. The range and standard deviation demonstrate considerable variation within most parameters measured. This variation was expected and was due to the high degree of natural variation between the soil types sampled.

pH

Plants and soil microorganisms respond strongly to their chemical environment, soil reaction (or pH) is an important chemical trait of soils. This trait is particularly important to plants because it influences the nutrients available for plant absorption and the concentration of toxic ions. In general, the soil is acid where precipitation is high enough to leach appreciable amounts of exchangeable bases from the soil and the soil is

TABLE 2

Chemical and Physical Traits of the Study Area[1]

Parameter	pH in Water	pH in 0.01M $CaCl_2$	Soluble Salt Electrical Conductivity mmhos/cm (2)	Soluble Salt Electrical Conductivity mmhos/cm (3)	Sodium Water Soluble (milliequivalents/100 g)	Sodium NH_4 Acetate Soluble (milliequivalents/100 g)	Cation Exchange Capacity (milliequivalents/100 g)	Exchangeable Sodium Percentage
Mean	8.4	7.8	0.89	3.5	1.02	2.87	37.0	5.0
Range	6.9-9.9	6.1-9.2	0.10-11.50	0.5-59.0	0.02-19.48	0.03-30.1	10.3-89.2	0.01-53.46
Standard Deviation	0.5	0.4	1.5	6.5	2.0	3.7	13.3	9.3

					Water Soluble					DTPA Extractable			
Parameter	Ammonium ppm	Nitrate ppm	Phosphorus $NaHCO_3$ Extractable ppm	Potassium Available ppm	Magnesium ppm	Calcium ppm	Potassium ppm	Sulfate ppm	Boron ppm	Copper ppm	Manganese ppm	Iron ppm	Zinc ppm
Mean	9.3	6.3	12.7	385.1	16.2	59.8	12.2	323.2	0.6	1.8	33.7	104.4	1.5
Range	0.4-35.2	<0.1-420.0	1.0-155.0	80.0-2540.0	0.4-319.7	3.6-679.0	0.9-190.0	5.0-6200.0	0.5-1.9	0.5-13.6	6-214	12-448	0.4-9.0
Standard Deviation	5.4	29.1	14.9	338.2	36.5	101.2	18.1	664.2	0.2	1.2	21.5	64.0	0.9

					Total							
Parameter	Molybdenum Anion Exchangeable ppm	Organic Matter %	Gypsum Requirement MEQ/100 g	Lime Requirement lb $CaCO_3$/acre	Phosphorus ppm	Arsenic ppm	Cadmium ppm	Chloride ppm	Chromium ppm	Cobalt ppm	Fluoride ppm	Mercury ppb
Mean	0.3	2.9	0.4	0	541.8	8.4	<0.5	910.0	44.4	8.0	510.0	18.8
Range	0.1-2.4	0.1-21.8	0.2-6.0	0	95-1549	5-40	<0.5-0.5	200-2500	20-80	1-35	160-1150	10-110
Standard Deviation	0.2	2.5	0.6	0	198.5	5.7	<0.01	330.8	9.8	2.6	194.0	12.0

	Total			NH_4 Acetate Extractable		Background Radioactivity				
Parameter	Antimony ppm	Vanadium ppm	Selenium Available ppb	Nickel ppm	Lead ppm	Uranium ppm	Equivalent Uranium ppm	Equivalent Thorium ppm	Potassium Radioactivity %	$Radium^{226}$ Picocuries/g
Mean	1.0	59.1	56.4	0.9	1.4	2.2	2.7	10.5	2.5	0.9
Range	1-3	20-110	10-2600	0.3-2.4	0.6-4.0	2-5	1-8	2-30	0.5-4.9	0.5-2.5
Standard Deviation	0.2	13.8	253.3	0.3	0.5	0.6	1.1	3.6	0.7	0.4

	Water-Holding Capacity, % (Dry Sample Wt. Basis)		Particle-Size Analysis, Wt. %			
Parameter	1/3 Bar Suction	15 Bar Suction	Sand -2.0 +0.05 mm	Silt -0.05 +0.002 mm	Clay -0.002 mm	Textural Class
Mean	25.7	12.6	39.1	47.0	13.9	Loam
Range	11.5-50.9	5.4-26.3	3.0-85.5	12.5-77.0	2.0-34.0	
Standard Deviation	7.3	3.5	17.4	13.8	6.3	

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(1) n = 312.

(2) Sample to extract ratio; 1 to 2.

(3) Conductivity for a saturation extract based on 1 to 2 ratio conductivity data and the 1/3 bar water-holding capacity.

alkaline where precipitation is generally insufficient to leach the exchangeable bases (especially calcium, sodium, and magnesium) from the soil.

The pH values (in water) for the study area range from slightly acid (6.9) to highly alkaline (9.9). The alkaline nature of almost all of the soils in the study area was expected and is typical of areas with low rainfall. Approximately 14 percent of the soil samples had a pH value greater than 8.9. These high pH values indicate that the sample contained alkali salts which might interfere with plant growth. Areas of alkali salt concentrations are identified and discussed in the section on exchangeable sodium percentage.

The measurement of pH in a calcium chloride solution has several advantages over the measurement of pH in water: 1) the pH determined in a calcium chloride solution is independent of silution over a wide range of soil-to-solution ratios, 2) the observed pH is essentially independent of the initial amount of salts present in the soil, and 3) the measured pH more nearly reflects the pH of the soil solution under field conditions. The values determined in a calcium chloride solution are about 0.5 pH units below the pH determined in water (Peech 1965). With this method, the pH in the study area ranged from 6.1 to 9.2 and averaged 7.8. These values are considered typical for semi-arid parts of the West.

The accurate way to express an average pH value (a logarithm) is to first convert pH to the hydrogen ion activity (an antilogarithm) for each observation, find the average hydrogen ion activity, and then convert this to the logarithmic pH. When an arithmetic average is calculated directly from from the pH values (as was done for data cited above) an error is introduced and the resulting pH is higher than the actual value. However, when pH

values fall within a rather narrow range, this error is slight. Over 50% of the samples taken in the study area had a pH value between the narrow range of 8.0 and 8.6.

Soluble Salt Electrical Conductivity

The concentration of dissolved salts in the soil is measured by the electrical conductivity of the soil solution. When conductivity of such a solution exceeds 4.0 mmhos/cm, the soil is classified as saline. Saline soils contain sufficient concentrations of soluble salts to restrict the growth of many plant species. However, plant response to saline conditions is species dependent (Hayward and Wadleigh 1949; Richards 1954).

Two measurements of soluble salt electrical conductivity were made on each soil sample. One measurement was made on the water extract obtained when one part of soil was mixed with two parts of water. The second measurement of conductivity adjusted the former value to reflect the concentration of soluble salts in a soil saturated with water. This second parameter has been correlated with plant growth and is the basis of the following discussion.

The electrical conductivity of the study area ranges from less than 1.0 mmhos/cm to a high of 59 mmhos/cm. When the electrical conductivity exceeds approximately 15.0 mmhos/cm, few plant species can survive, and those that are able to grow may be restricted in their yield (Barth, 1976). The highly saline samples are listed as follows:

Site No.	Sampling Depth, cm	Electrical Conductivity mmhos/cm
13	0-10	29.4
13	10-50	59.0
44	100-150	14.5
47	100-150	39.0
48	50-100	18.0
50	100-150	29.6
51	50-100	23.5
61	100-150	41.6
66	0-10	20.0
66	10-50	39.4
66	50-100	19.6
71	10-50	18.2
74	50-100	16.6
74	100-150	17.2

With few exceptions, these highly saline samples occurred in the 50-100 cm or 100-150 cm sampling interval, and the 0-10 cm and 10-50 cm intervals were either nonsaline or slightly saline. The general absence of highly saline material at or near the surface apparently mitigates the detrimental effects of salts on plant growth. Sites 44, 47, 48, 50, 51, 53, 61, and 74 supported vegetation that was similar (in terms of species and visual density) to sites where highly saline subsurface intervals were not found. When the highly saline interval was at the surface or in the 10 to 50 cm interval (as is the case on sites 13, 66, and 71), plant species composition reflected the presence of the salt. Shadscale dominated two of these sites with the remaining site (site 66) being dominated by rye grass. Both species appear salt tolerant.

Cation Exchange Capacity

The cation exchange capacity is the sum total of exchangeable cations that a soil can absorb. Clay minerals and humus account for essentially all

of the exchange capacity of a soil. When the average cation exchange capacity of the study area was related to the percentage clay, the exchange capacity is approximately 250 meq/100 g. This relatively high exchange capacity indicates that montmorillonite is the dominant clay mineral and that soil humus accounts for a substantial amount of the exchange capacity. Montmorillonite is the clay mineral most commonly found in semi-arid regions.

Exchangeable Sodium Percentage

The exchangeable sodium percentage (ESP) expresses the percentage of sodium ions on the soil exchange complex. When this percentage exceeds 15.0, the soil is termed sodic (or alkali). Clay particles in a sodic soil repel one another and create a dispersed condition. Water penetration into a dispersed soil is very slow, thus increasing the erosion potential and reducing the amount of soil water available for plant use. Sodic soils may restrict root elongation and development due to 1) the dispersed condition, 2) the poor soil structure, 3) the restricted water movement into and through the sodic soil, and 4) the poor aeration sometimes found in sodic material. A given level of ESP is more detrimental to plant growth in a soil with a high percentage clay than with a low percentage clay. This is due to the greater degree of particle dispersion in a clayey soil than in a sandy soil (Pearson and Bernstein 1958; Pearson 1960).

Mean ESP for the study area was 5.0 and ranged from less than 1 to 53 (Table 2). Sodic intervals were found on 25 sampling sites, and 11% of the samples collected were sodic. These sodic intervals are as follows:

Site No.	Sampling Depth, cm	ESP	Site No.	Sampling Depth, cm	ESP
12	100-150	17.7	41	50-100	19.8
13	0-10	53.5	42	50-100	43.2
13	10-50	21.9	42	100-150	48.5
19	50-100	28.1	44	100-150	21.4
19	100-150	36.1	45	10-50	36.1
20	100-150	34.4	45	50-100	48.2
21	50-100	32.8	47	50-100	28.4
21	100-150	42.1	47	100-150	17.0
22	50-100	31.3	51	100-150	35.9
22	100-150	36.7	52	50-100	21.9
23	100-150	16.0	58	100-150	23.7
24	50-100	15.2	61	50-100	25.7
24	100-150	28.0	63	50-100	43.0
25	50-100	22.5	66	50-100	19.3
26	50-100	38.7	74	50-100	18.5
30	50-100	29.6	74	100-150	16.4
36	50-100	15.4	77	50-100	19.5

In only 3 of the 34 samples did a sodic layer occur in the 0-10 cm or 10-50 cm interval. Apparently, the sodic condition is not generally found at depths shallower than 50 cm. It is probable that this sodic condition is a trait of the parent material. The soils in the study area are shallow and in almost all cases parent material is encountered in the 50-100 cm sampling interval. Sodium that may have been in or near the surface probably leached out or was replaced by other salts.

The subsurface sodic intervals appear to have little effect on the vegetation. Pinyon-juniper or sagebrush dominated most of the sites where sodic intervals were found. Vegetation on these sites appeared to be the same as the vegetation found on sites where sodic intervals were not present. On sites where the sodic intervals were at the surface or in the 10-50 cm interval (as on sites 13 and 45) the vegetation was greasewood or shadscale.

Apparently, these shrubs are adapted to sodic conditions.

With only one exception, the sodic soils were either a loam or a sandy loam and contained less than 15% clay. Therefore, the ESP is not as restrictive to plant growth and water infiltration as might be inferred from the numerical value.

Sodic soil can be converted to a nonsodic status through the application of various chemical ammendments. These ammendments, directly or indirectly, add water soluble calcium to the soil. This calcium then replaces the sodium held on the exchange complex of the soil. The soil is then leached to remove the sodium which is now in a water soluble form. Of the various amendments available, gypsum is the most common and least expensive (Barth 1976).

Plant Macronutrients

Of the elements necessary for normal plant growth, nitrogen, phosphorus, potassium, magnesium, calcium, and sulfur are required in relatively large quantities. These elements are referred to as macronutrients.

Nitrogen. There are three major forms of soil nitrogen: 1) organic nitrogen associated with soil humus, 2) ammonium nitrogen associated with clay minerals (also termed exchangeable nitrogen), and 3) soluble nitrate compounds (Brady 1974). Most of the soil nitrogen is in organic form and is slowly released, through microbial action, as ammonium and nitrate. Positively charged ammonium is attracted and held by negatively charged clay minerals. In contrast, nitrate has a negative charge and, consequently, it is highly mobil in the soil. Plants are able to absorb both the ammonium and the

nitrate forms of nitrogen. However, in most cases ammonium is converted to nitrate prior to plant absorption. This nitrification process requires nitrifying bacteria, a carbon source, oxygen, water, and favorable ambient temperatures.

The nitrogen level in soils used for crop production is commonly kept at approximately 40 ppm (80 lbs per acre). The soils in the study area, as in most other natural systems, contained substantially less nitrogen that is advised for agricultural soils. The concentration of nitrate plus ammonium averaged 15.6 ppm (approximately 31 lbs per acre). While this amount of nitrogen is low from a crop production standpoint, it appears adequate for natural systems. Plants in the study area were not visually suffering from a deficiency in nitrogen, although plant growth may increase if nitrogen were applied to the soil.

In some locations there were unusually high concentrations of nitrate. The following samples contained more than 30 ppm of nitrate:

Site No.	Sampling Depth, cm	Nitrate, ppm
5	100-150	165.0
13	0-10	62.6
13	10-50	37.6
18	50-100	39.4
44	50-100	94.0
48	50-100	42.4
55	100-150	83.6
72	100-150	46.8
74	10-50	61.0
74	50-100	191.0
74	100-150	420.0

With only one exception, the high levels of nitrate occurred below the soil surface. Sites 18, 44, and 74 had been burned within the last 10 years, as evidenced by charred sagebrush stumps in the area. An increase in soil

nitrate is often noted following burning. Other events are involved in nitrate accumulation. Nitrification can occur during periods of plant dormancy. Without plant uptake, this nitrate is leached from the surface soil and may accumulate at deeper depths. The presence of buried soil horizons can also be asource of subsurface nitrate. Delwiche (1956) stated that the common association of high nitrate levels with arid soils is probably not a result of a more active nitrification in such soils, but is related to the general accumulation of salts resulting from the evaporation of water. Whatever the cause, this subsurface accumulation of nitrate in some sections of the study area appeared to have little, if any, affect on plant growth or species composition.

Phosphorus. With the possible exception of nitrogen, no other element has been as critical in plant growth as phosphorus. The lack of sufficient amounts of plant-available phosphorus curtail many physiological processes and also prevent plants from obtaining other nutrients. Phosphorus deficiency is probably the most critical mineral deficiency in grazing livestock (Allaway 1975). As with most other plant nutrients, phosphorus is supplied by mineral elements in the soil and by organic plant residues. Extractable (or plant available) phosphorus in the study area ranged from 1 ppm to 155 ppm and averaged 12.7 ppm. Plants normally do not suffer from phosphorus deficiency until the extractable level falls well below 10 ppm. Few surface soil samples in the study area contained less than 10 ppm of extractable phosphorus. The surface soil receives a substantial amount of phosphorus from plant residue while the subsoil phosphorus is derived mainly from minerals. The two samples containing the highest amount of phosphorus

(155 and 130 ppm) were surface soils under the canopy of large, old pinyon trees.

Total phosphorus was also measured on all soil samples. Values ranged from 95 to 1549 ppm and averaged 542 ppm. Shacklette, Hamilton, Boerngen and Bowles (1971) found that total phosphorus in soils averaged 420 ppm and ranged from 20 to 6,000 ppm. Black (1968) cites 620 ppm as the average phosphorus concentration in soils. Total phosphorus in the study area was within the range cited in the literature as being normal for surface soils. Most of the total phosphorus present in soils in unavailable to plants (Brady 1974) and the measurement of total phosphorus gives no indication of plant response to this nutrient.

Potassium. Most of the potassium in the soil is held as part of the primary minerals or is fixed in forms that at best are only moderately available to plants. Potassium found in the soil solution and on exchange sites is available for plant absorption. This form of potassium ranged from 80 to 2540 ppm in the study area and averaged 385 ppm. Plants require approximately 150 ppm of available potassium for normal growth. Intervals with less than 150 ppm of potassium are essentially confined to the subsoil and had no noticeable influence of plant growth.

Macronutrients Measured in Water Soluble Forms. The concentration of magnesium, calcium, potassium, sulfate, and sodium were measured in a water extract. With the exception of sulfate, these elements also exist in an exchangeable form and the water soluble concentration may be only a

small fraction of the total amount available to plants. These nutrients are rarely deficient in semi-arid environments. More commonly, they are present in excessive amounts as salts and limit the ability of plants to absorb water. This salinity aspect has been previously discussed.

As an integral part of the chlorophyll molecule, magnesium is essential to all green plants. This element is also essential to animals and when forage contains insufficient amounts of magnesium, a disorder known as grass tetany can occur in lactating cows (Allaway 1975). Water soluble magnesium in the study area averaged 16.2 ppm and ranged from 0.4 to 319.7 ppm. These values appear typical of semi-arid areas and suggest that the magnesium level is sufficient for both plants and animals.

The concentration of water soluble potassium averaged 12.2 ppm for the study area. This is only 3% of the available potassium, apparently most of the plant-available potassium is found on the exchange sites of clay minerals and soil humus.

Since soils of semi-arid regions are frequently rich in calcium, calcium deficiencies in plants or animals are rare. Water-soluble calcium ranged from 3.6 to 679.0 ppm and averaged 59.8 ppm in the study area. It is probable that substantially more calcium exists on the soil exchange complex.

Sodium is required for the normal growth of some plants, such as Atriplex vesicaria (Brownell and Wood 1956), but it is not a universal plant nutrient. The water-soluble concentrations of sodium in the study area and in most areas of the West are ample to meet the

requirements of those species requiring sodium. Sodium more often limits plant growth through its contribution to soil salinity.

Sulfur is used in the formation of many proteins and as such is essential for both plants and animals. Only 2% of the intervals tested in the study area contained less than 10 ppm sulfate. Soils are not considered sulfur deficient until the level of sulfate is less than approximately 10 ppm.

Plant Micronutrients

Elements which are needed in relatively small amounts by plants are termed micronutrients and include the elements of boron, molybdenum, copper, iron, zinc, chloride and manganese. For unhindered plant development, these micronutrients must be present in amounts sufficient to meet plant demands, they must occur in proper balance, and these micronutrients cannot be concentrated in amounts which would be toxic to plants or to animals ingesting these plants.

Boron. Boron is essential for plant growth, but the amount required is small and if exceeded, this boron is phytotoxic (plant toxic). Plants vary considerably in their boron requirements and in their tolerance to excessive boron (Richards 1954). In addition, there appears to be an overlap between beneficial and injurious effects of boron, and any conception of an optimum concentration of soil boron becomes theoretical and relative to numerous factors (Eaton 1944). The boron content of the soils of the study area ranged from less than 0.5 ppm to 1.9 ppm and averaged 0.6 ppm. Boron concentrations in this range should not restrict plant growth in the study area from either a deficient or toxic extreme.

Copper. Kubota (1975) found that the total copper concentration in soils derived from shales averaged 18.7 ppm. Other authors cite values from 14 to 30 ppm as the average concentration of total copper. From 10 to 50 percent of the total copper in soils is in a plant-available form (Mitchell 1964), thus plant-available copper should average from approximately 2 to 9 ppm. Extractable copper in the study area ranged from 0.5 to 13.6 ppm and averaged 1.8 ppm. These parameters suggest that the copper concentration in the study area is normal for soil and not restrictive to plant growth.

Manganese. Manganese is an essential component of plant and animal tissues and is among the least toxic of the trace elements to animals (Underwood 1971). However, manganese phytoxicities are not uncommon in very acid soils or water-logged soils (Kubota and Allaway 1972), but cases of manganese toxicity in undisturbed semi-arid regions of the West have not been observed. In prairie soils, extractable manganese averaged 48.7 ppm (Wali and Freeman 1973). The manganese concentration of the study area averaged 34 ppm and ranged from 6 to 214 ppm, with only three of the 312 soil samples having more than 100 ppm extractable manganese. The manganese concentration in the study area does not suggest the possibility of deficiency or toxicity problems.

Iron. While iron is least available in alkaline soils, iron deficiencies in nonagricultural areas of the West are probably uncommon. Cases of iron toxicities under natural conditions have not been documented (Wallihan 1966),

even when the total iron concentration exceeds 5% (Murphy and Walsh 1972). Soils in the study area averaged 104 ppm extractable iron and the lowest concentration was 12 ppm. Ryan, Stroehlein, and Miyanoto (1975) reported that the DTPA extractable iron in rangeland soils was not considered deficient until the concentration dropped below approximately 2 ppm.

Zinc. Extractable zinc in soils commonly ranges from less than 1 ppm to 40 ppm, although some plants have been grown on soils containing more than 700 ppm extractable zinc with no apparent toxicity (Singh and Steenberg 1975; Mitchell 1964). Zinc requirements of animals are commonly higher than that found in plants, and research indicates that zinc fertilization of food and feed crops may be very useful in improving plants as a source of dietary zinc (Allaway 1975; Underwood 1971). An extractable zinc level of less than 0.8 ppm is considered deficient for crops such as corn, but zinc deficiencies have not been reported in noncultivated areas. The DTPA extractable zinc in the study area averaged 1.5 ppm and ranged from 0.4 to 9.0 ppm. While many interval samples had less than 0.8 ppm zinc, at least one interval at any given sampling site had more than 0.8 ppm zinc; in no case was the entire plant rooting zone deficient in zinc. Zinc deficiency symptoms were not noted in the vegetation growing in the study area. However, supplemental forms of zinc may increase animal weight gain.

Molybdenum. While molybdenum is essential for normal plant development, plants occasionally accumulate large amounts of this element. If sufficient amounts of such plants are eaten by ruminants, a nutritional

disorder known as molybdenosis develops (Johnson 1966, Kubota 1975). Plants growing on wet alkaline floodplains and on alkaline alluvial fans are more prone to accumulate toxic amounts of molybdenum than plants growing on upland sites (Kubota 1975). The total molybdenum content of soil averages 2 ppm and the most commonly cited upper range for total molybdenum is 5 ppm (Hawkes and Webb 1962; Swaine and Mitchell 1960; National Academy of Sciences 1972). Information on the expected soil concentration of anion exchangeable molybdenum is lacking, but extensive analysis of overburden samples has shown that the concentration of this form of molybdenum is rarely greater than 1.0 ppm.

Intervals containing more than 1.0 ppm exchangeable molybdenum are as follows:

Site No.	Sampling Depth, cm	Anion Exchangeable Molybdenum ppm
63	0-10	1.2
66	10-50	1.2
73	50-100	1.3
73	100-150	1.2
99	0-10	1.2
101	0-10	1.1

Sites 99 and 101 were within 200 feet of each other and both were located next to the bole of large pinyon pines. This apparent influence of vegetation on soil traits is discussed in a later section. The remaining three sites were widely scattered and there appeared to be no common factor explaining the occurrence of these soils high in molybdenum. The vegetation growing on these sites may have contained relatively high amounts of molybdenum, but

because of the scattered nature of the high molybdenum soils, ruminants grazing in these areas are unlikely to be adversely affected.

Chloride. Chloride is the most recent element to be confirmed as essential to plant growth. However, chloride deficiencies in field situations have not been positively identified and suspected deficiencies are rare. The lack of deficiencies is related to the facts that plants require very little chloride for normal growth and that chloride is widely distributed in nature. Large quantities of this element are annually carried inland from the oceans and deposited on the soil surface with rain. Deposition of 12 to 35 pounds of chloride per acre are common, and deposition of 100 pounds per acre or more near the coast are not unusual. Cases of chloride toxicity have been documented and usually occur in poorly drained areas that receive runoff from other areas and in regions along the coast (Eaton 1966).

The chloride found in the soils of the study area appeared to be of the magnitude expected for semi-arid alkaline regions.

Organic Matter

Organic matter influences the chemical and the physical traits of soil far out of proportion of the small quantities generally present. Organic matter commonly accounts for at least half of the cation exchange capacity of soils and is very important in the stability of soil aggregates. In addition, organic matter supplies energy and other constituents necessary for microbial activity. Soil organic matter generally ranges from less than 1% to 10% and averages approximately 3% in arid areas (Brady 1974). Both precipitation and

temperature have been recognized as important factors in determining the organic matter content of soils (Jenny 1941).

In the study area, soil organic matter averaged 2.9%, a value typical of arid areas. The range in percentage organic matter was from 0.1 to 21.8. Intervals with less than 1% organic matter were generally confined to the 50-100 and 100-150 cm sampling intervals. Samples containing more than 10% organic matter were confined to the surface sampling interval and occurred on sites where there was an unusually deep accumulation of litter.

Gypsum Requirement

The gypsum requirement is an attempt to determine the amount of calcium required to replace the sodium on the soil exchange complex when data on the cation exchange capacity and exchangeable sodium are not available. Determining this requirement involves the use of an arbitrary procedure and does not measure a distinct chemical property of the soil. The gypsum requirement is positively correlated with the exchangeable sodium by means of a regression equation (Richards, 1954). The use of gypsum to reclaim sodic soils has been previously discussed. Briefly, the gypsum supplies water-soluble calcium to the soil. This calcium then replaces the sodium held on the soil exchange complex.

Lime Requirement

The lime requirement tells how much $CaCO_3$ or its equivalent that must be applied to the soil to increase the pH to 7.0 (Peech 1965). The lowest pH in the study area was 6.9, and this very slight degree of acidity would not affect plant growth. Generally, the soil pH is well below 6.0 before the use of lime is considered. As expected, the lime requirement for

all the soil samples collected in the study area was zero.

Trace Elements

Those elements which are not essential for normal plant growth, but which may be absorbed and accumulated by plants, are discussed in this section. The concentration of certain trace elements in the soil and the subsoil are of interest because plants may absorbed enough of a particular trace element to be a potential threat to domestic or wild herbivores. Through various indirect means, trace elements in soils can be transferred to humans. It is also possible that high soil concentrations of some trace elements will be phytotoxic.

Arsenic. The mean concentration of total arsenic in soils varies between 5 and 10 ppm (Lisk 1972). Allaway (1975) gives 40 ppm as the maximum content of arsenic normally found in soil, while Mitchell (1964) found an upper value of 70 ppm. Liebig (1966) stated that arsenic is more concentrated in the soils of arid regions than in soils of mesic regions. He further stated that dangers from arsenic poisoning are greatest where dust high in arsenic adheres to plant surfaces rather than the consumption of plants containing arsenic.

In the study area, total arsenic ranged from 5 to 40 ppm and averaged 8.4 ppm. In view of the literature cited above, these soils are not unusual in their content of arsenic.

Cadmium. Cadmium, a toxicant to man and other living organisms in virtually all of its chemical forms, is found mainly in various zinc ores. Cadmium and zinc appear to compete for certain organic ligands and zinc

has an ameliorative effect on cadmium toxicity. The cadmium concentration of surface soils is generally less than 1 ppm. Soils with more than 1 ppm cadmium have usually been contaminated by agricultural or industrial chemicals (National Academy of Sciences 1974; Page and Bingham 1973).

Some soil properties appear to influence plant absorption of cadmium. Williams and David (1973) noted that plant uptake of cadmium was substantially lower in soils with a high cation exchange capacity than in soils with a low cation exchange capacity. Lagerwerff (1971) and Lisk (1972) found that while many plants easily absorbed cadmium from the soil, absorption decreases as pH increases.

The soils of the study area consistently contained less than 0.5 ppm of total cadmium, and a concentration of this magnitude is expected for undisturbed areas. It is probable that the average concentration of total cadmium in the study area is substantially below the detection limit of 0.5 ppm. A study of the soils of the Piceance Creek Basin and other areas in northwestern Colorado found the total cadmium averaged 0.13 ppm and ranged from 0.017 to 0.570 ppm (Mahmoud 1977).

Chromium. Chromium is widely distributed in nature and while there is no conclusive evidence showing that it is essential for plant growth, chromium is required by animals. However, the overall nutritional significance and biochemical role of chromium is unknown. Cases of chromium toxicity are rare and a wide margin of safety exists between the amounts

generally ingested and those likely to induce injury (Norrish 1975; Pratt 1966; Underwood 1971). Chromium as a plant toxicant has been recognized since the turn of the century, but natural occurring toxicities appear to be limited to serpentine soils where the chromium content ranges from 2000 to 3500 ppm (Pratt 1966; Swaine and Mitchell 1960). After measuring the chromium in soils of conterminous United States, Shacklette, Hamilton, and Boerngen (1971) concluded that total chromium averaged 53 ppm and ranged from 1 to 1500 ppm.

For Tract C-a and adjacent areas, total chromium ranged from 20 to 80 ppm and averaged 44 ppm. These values are very close to the average chromium content of soils as mentioned above.

Cobalt. Animals, especially ruminants, require an adequate supply of cobalt in their diet and soils should contain approximately 7 ppm total cobalt to support healthy livestock. Some soil microorganisms, notably those that are responsible for nitrogen fixation, also require cobalt (Mitchell 1964; Swaine and Mitchell 1960). Alkaline soils quickly convert soluble cobalt to forms that are not available to plants and cobalt fertilization may be effective in preventing cobalt deficiencies in ruminants. Excessive levels of cobalt are not very toxic to either plants or animals (Allaway 1975). Hawkes and Webb (1962) found that soils average 8 ppm in total cobalt and range from 1 to 40 ppm. Numerous other investigators have reported similar values.

An average of 8 ppm and a range of 1 to 35 ppm total cobalt was

found in the study area. This average and range is almost identical to that cited by Hawkes and Webb (1962). Vegetation in some portions of the study area may not contain sufficient cobalt to support rapid animal development. However, such areas may be localized and insignificant when the overall grazing pattern is considered.

Fluoride. The earth's crust contains about 800 ppm fluoride and soils range from 10 to 7070 ppm in fluoride. Neutral and alkaline soils inactivate fluoride, probably in a reaction with calcium and other soil constituents that convert soluble fluoride to insoluble forms. Thus, the plant fluoride content is not appreciably affected by the amount of total fluoride in the soil. While excessive fluoride can be very toxic to plants and animals, cases of toxicity are limited to very acid soils and industrialized areas with high atmospheric levels of fluoride (National Academy of Sciences 1972; Allaway 1975).

Soils of the study area contained from 160 to 1150 ppm total fluoride and averaged 510 ppm. These levels appear normal and nontoxic for alkaline or mildly acid soils.

Mercury. Mercury occurs widely in low concentrations in the biosphere and has long been known as a toxicant. This element is considered nonessential for living organisms. The mercury content of soils is generally low, and the average concentration of total mercury in soils is approximately 100 ppb (Potter, Kidd, and Standiford 1975; Shacklette, Boerngen, and Turner 1971; Kothy 1973). The average concentration of mercury for the

study area was 19 ppb, a level substantially below the average soil concentration. The highest level of mercury detected in the study area was 110 ppb. As much as 4600 ppb of mercury has been found in supposedly uncontaminated surface soils (Shacklette, et al. 1971).

Antimony. In soils termed as normal podzols, total antimony had a rather uniform value of 2.1 ppm and ranged from 1.6 to 2.4 ppm (Presant 1971). In studies of soils in the Powder River Basin of Wyoming and Montana, antimony in the surface and subsurface soil ranged from 0.60 to 2.1 ppm (Anderson, Keith, and Connor 1975). In the study area, antimony averaged 1 ppm and ranged from less than 1 ppm to 3 ppm. These low values appear to be normal for surface and subsurface soils.

Vanadium. Vanadium is a component of all soils and small amounts of this element are normally absorbed by plants. Clear proof that this element is required by higher plants or by higher animals has yet to be produced. However, some species of algae and bacteria require vanadium and there is increasing evidence that many animals require small amounts of vanadium. Under field conditions, there have been no reports of vanadium deficiencies or toxicities (Underwood 1971; Pratt 1966). The normal concentration of vanadium in soil is approximately 100 ppm and the range is from about 20 to 500 ppm (Mitchell 1964; Lisk 1972; and others). In Trace C-a and adjacent areas, the vanadium averaged 59 ppm and ranged from 20 to 110 ppm, thus indicating a normal concentration of vanadium in these soils.

Selenium. Trace amounts of selenium can be detected in most soils and excessive amounts can occur in arid areas where the soil is derived from seleniferous rock and precipitation is insufficient to leach the selenium below the plant rooting zone. When this element is present in excessive amounts in the soil, it can inhibit the growth of some plant species. But a more serious problem arises when plants absorb excessive selenium from the soil and these plants are then ingested by livestock. The resulting disease known as "blind staggers" or "alkali disease" commonly results in death of the affected animal. However, selenium is an essential element for proper animal development and the total area of the world affected by selenium deficiency is far greater than those areas affected by selenium excess (Beath 1959; Patel and Mehta 1968; Underwood 1971). Normal soils contain from 100 to 2000 ppb total selenium and from less than 10 to approximately 500 ppb water-soluble selenium (Swaine and Mitchell 1960; Patel and Mehta 1968). The range of available selenium has yet to be established for soils, but would have an upper range between 500 and 2000 ppb.

The available selenium in the soils of the study area averaged 56 ppb and ranged from 10 to 2600 ppb. Soils containing 1000 ppb or more of available selenium could be considered unusual. Soils in this category occurred in the study area, but outside the boundaries of Tract C-a, as follows:

Site No.	Sampling Depth, cm	Available Selenium, ppb
44	50-100	1000
44	100-150	1200
61	100-150	1900
66	0-10	2400
66	10-50	2600
66	50-100	1300

It is possible that plants growing on these soils will accumulate excessive selenium; plant analysis would confirm or reject this possibility.

Nickel. Completely convincing evidence that nickel, a relatively nontoxic element, is essential for plants and animals has not yet appeared. Cases of nickel toxicities are rare, but may occur naturally on serpentine soils which are typically high in nickel. Swaine and Mitchell (1960) found that ammonium acetate extractable nickel ranged from 3.5 to 11.8 ppm for well-drained podzol soils. Several investigators have found that approximately 10 ppm of ammonium acetate extractable nickel was phytotoxic (Vanselow 1966).

The soils contained within the study area averaged 0.9 ppm of ammonium acetate extractable nickel and ranged from 0.3 to 2.4 ppm. Based on the above information, these levels are normal for soils and nontoxic to plants.

Lead. There has been considerable biological interest in lead in recent years, with most of this research centered on the toxic properties of lead as an industrial hazard to man and to animals. In uncontaminated areas, lead is a natural component of soils and is of little consequence to plants and to animals. Plant uptake and translocation of lead is minimal under normal conditions. Factors that influence lead movement include soil traits and the presence of ligands that complex with lead and prevent its movement across cell walls and throughout the plant. Thus, plants effectively exclude most lead from above-ground parts and the small amount of lead that is translocated to shoots and leaves is of little consequence to

grazing animals. Lead ingested by livestock, under usual conditions, is largely sequestered in bone and is not transferred to the human food cycle (Rains 1975; National Academy of Sciences 1974; Wilson and Cline 1966; and others). Working in Scotland, Swaine (1955) found that surface soils averaged 0.45 ppm and ranged from 0.05 to 3.60 ppm of ammonium acetate extractable lead.

Tract C-a and adjacent areas contained from 0.5 to 4.0 ppm ammonium acetate extractable lead and averaged 1.4 ppm. While these levels are slightly higher than those found by Swaine, there is no indication that the level of soil lead is of any unusual biological significance in the study area.

Background Radioactivity

Background radioactivity was measured in terms of the concentration of uranium (or chemical uranium), equivalent uranium, equivalent thorium, radioactive potassium, and radium. These data served to quantify the baseline radioactivity of the study area.

Chemical uranium averages 2.7 ppm for the earth's crust, 3.2 ppm in shale, and 4.8 ppm in granite (Krauskopt 1967). Equivalent uranium is of the same general magnitude as chemical uranium, while equivalent thorium is approximately 3 times the concentration of chemical uranium. If a system is in equilibrium, 1 ppm of chemical uranium contains 0.43 pico curies per gram of radium 226. High amounts of radium can be a radiological hazard. However, chemical uranium becomes a chemical toxicant long before it becomes a radiation hazard. Total potassium in the earth's crust averages

approximately 2.5% and, by convention, this figure is reported as potassium radioactivity in background radioactivity data. However, only 0.0118% of the total potassium is radioactive and in most soils this potassium contributes most of the radioactivity (Bowen 1966).

The background radioactivity of the study area is low and within the ranges expected. None of the soil samples collected show any unusual concentrations of the various components of background radioactivity and pose no danger to living organisms. These soils are slightly out of radiological equilibrium, but this is the general case with soils. Because the chemical uranium is slightly less than equivalent uranium, the radium is slightly greater than would be expected on the basis of chemical uranium alone. This slight deviation from equilibrium is common for soils where chemical uranium is subject to removal via weathering.

Water-Holding Capacity

The water-holding capacity measures the amount of water retained by a soil at a given level of suction. When measured at 1/3 bar (4.85 psi) suction pressure, the water-holding capacity approximates the amount of water retained by a soil after free drainage has ceased. The capacity at 15 bars (220 psi) suction pressure approximates the upper limit at which most plants are unable to absorb water from the soil. The amount of water retained between these two extremes is termed the plant-available moisture capacity, and serves as an index to the amount of water available for plant absorption. Nishimura (1974) suggested that soil used in reclamation has a minimum

plant-available moisture capacity of approximately 7% to insure that the soil has the potential to retain sufficient water for normal plant growth. Soil texture, structure, and organic matter are the main factors in determining water-holding capacity.

Approximately 5% of the soils collected in the study area had a plant-available moisture capacity of less than 7%. These samples were located at sites 45, 67, 68, 70, 71, and 109. The lack of water retention by these soils may restrict plant growth or restrict plant composition to drought-tolerant species.

Texture

Texture is an important physical trait of soils in that it influences the nutrient-supplying ability of soil as well as the supply of air and water to plant roots. Optimum soil texture varies with climatic conditions. In semi-arid regions, the production of native vegetation is greater on sandy soils than on medium to fine textured soils. In sandy soils, the infiltration rate is rapid so there is little water loss through surface runoff. Additionally, less moisture is held per unit depth in sandy soils so less moisture is lost to surface evaporation. However, sufficient fine-textured material must be present to retain adequate amounts of water (Berg and Barrau 1973).

Soils of the study area were generally in the loam category and ranged from a loamy sand to a clay loam. Most soils were in the coarse to medium texture categories.

Soil Properties as a Function of Depth

During the process of soil formation, rearrangement occurs in which many soil constituents are concentrated in certain portions of the soil profile. There are basically two processes which develop vertical patterns in soil. One process involves the leaching of water soluble components as water moves through the soil. The second process involves the redistribution of elements by plants. In the cycle of elements through the soil-plant system, plants bring about changes in the vertical distribution of nutrients, organic matter, and other soil constituents by virtue of their rooting, litterfall, and decomposition characteristics. This process has been described by a number of investigators.

The soils of the study area were grouped on the basis of sampling depth and each soil trait statistically evaluated for its change as a function of sampling depth (Table 3). It is important to note that factors other than sampling depth alone may have influenced the presence or absence of vertical differentiation. Variables such as parent material, vegetation, relief, and micro-climate may have had a significant influence on vertical differentiation.

pH

Soil pH increased as depth increased, a trait common to many soils. As organic matter decomposes, various acids are produced and released to the soil. Decomposition is most intense in the surface soil and decreases sharply with increasing depth. In addition, leaching removes carbonates

TABLE 3

Soil Traits as Influenced by Sampling Depth[1]

Depth, cm		pH in	pH in	Soluble Salt Electrical Conductivity	Soluble Salt Electrical Conductivity	Sodium Water Soluble	Sodium NH_4 Acetate Soluble	Cation Exchange Capacity	Exchangeable Sodium
From	To	Water	0.01M $CaCl_2$	mmhos/cm (2)	mmhos/cm (3)	(milliequivalents/100 g)			Percentage
0	10	8.2a	7.6a	0.61a	2.3a	0.54a	1.63a	42.1a	3.2a
10	50	8.4a	7.8ab	0.72a	3.0a	0.80a	2.06a	38.6a	3.9a
50	100	8.8b	8.0ab	1.03b	4.6b	1.44b	4.43b	32.1b	11.6b
100	150	8.7b	8.1b	1.67c	7.7c	1.97c	5.13b	29.1b	12.8b

Depth, cm		Ammonium	Nitrate	Phosphorus $NaHCO_3$ Extractable	Potassium Available	Water Soluble					DTPA Extractable			
						Magnesium	Calcium	Potassium	Sulfate	Boron	Copper	Manganese	Iron	Zinc
From	To	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
0	10	11.7a	3.2a	20.1a	558.9a	10.4a	48.9a	16.4a	229a	0.7a	1.7a	48a	110a	1.8a
10	50	9.1b	2.8a	9.3b	315.4b	15.9a	72.8a	9.8b	352a	0.6a	1.9a	31b	104a	1.4b
50	100	7.8b	7.4a	8.8b	273.9b	18.1a	49.2a	9.7b	326a	0.7a	1.7a	24b	104a	1.3b
100	150	6.9b	19.9b	10.1b	321.5b	27.3a	71.9a	11.9b	472a	0.6a	1.8a	21b	93a	1.2b

Depth, cm		Molybdenum Anion Exchangeable	Organic Matter	Gypsum Requirement	Lime Requirement	Total							
						Phosphorus	Arsenic	Cadmium	Chloride	Chromium	Cobalt	Fluoride	Mercury
From	To	ppm	%	MEQ/100 g	lb $CaCO_3$/acre	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppb
0	10	0.3a	4.5a	0.3a	0	581a	8a	0.5a	836a	45a	8a	480a	17a
10	50	0.3a	2.9b	0.3a	0	523a	9a	0.5a	867a	44a	8a	504a	20a
50	100	0.3a	1.8b	0.4ab	0	516a	8a	0.5a	1006b	43a	8a	536a	19a
100	150	0.3a	1.3b	0.6b	0	537a	8a	0.5a	1028b	47a	8a	550a	18a

Depth, cm		Total		Selenium	NH_4 Acetate Extractable		Background Radioactivity				
		Antimony	Vanadium	Available	Nickel	Lead	Uranium	Equivalent Uranium	Equivalent Thorium	Potassium Radioactivity	$Radium^{226}$ Picocuries/
From	To	ppm	ppm	ppb	ppm	ppm	ppm	ppm	ppm	%	g
0	10	1a	60a	43a	0.8a	1.4a	2.2a	2.6a	10.6a	2.7a	0.9a
10	50	1a	60a	49a	1.0b	1.5b	2.2a	2.7a	10.2a	2.4b	1.0a
50	100	1a	57a	63a	0.8a	1.3a	2.2a	2.7a	10.5a	2.4b	0.9a
100	150	1a	59a	97a	0.8a	1.3a	2.4a	2.8a	11.0a	2.4b	0.9a

Depth, cm		Water-Holding Capacity, % (Dry Sample Wt. Basis)		Particle-Size Analysis, Wt. %			
				Sand	Silt	Clay	
From	To	1/3 Bar Suction	15 Bar Suction	-2.0 +0.05 mm	-0.05 +0.002 mm	-0.002 mm	Textural Class
0	10	25.6a	13.0a	37.1a	48.7a	14.2a	Loam
10	50	26.5a	13.3a	37.1a	48.6a	14.3a	Loam
50	100	25.7a	12.0a	42.2b	44.2b	13.6a	Loam
100	150	23.0a	11.0b	43.8b	43.4b	12.7a	Loam

(1) n = 100 for 0-10 cm and 10-50 cm sampling depths; n = 69 for 50-100 cm depth; n = 43 for 100-150 cm depth.
(2) Sample to extract ratio: 1 to 2.
(3) Conductivity for a saturation extract based on 1 to 2 ratio conductivity data and the 1/3 bar water-holding capacity.
(4) Within any given column, figures that lack one or more common letters are significantly different at the 95% level.

from the surface and deposits them lower in the soil profile. Such processes develop gradients in soil pH.

Electrical Conductivity

The electrical conductivity increased from 2.2 mmhos/cm at the soil surface to 7.7 mmhos/cm at the 100-150 cm depth. This increase in salinity with depth is due, in part, to the leaching of water soluble salts from surface to the subsurface. Other factors may also be involved. In many sections of the study area, aeolian material has been deposited on the original surface. This aeolian material may have contained less soluble salts than the original surface. Thus, surface and near surface soil samples were of one geologic origin while the deeper samples were of another geologic origin.

Cation Exchange Capacity

The cation exchange capacity is highest at the surface and lowest in the 100-150 cm sampling depth. This decrease reflects the vertical distribution of organic matter and of clay, the two soil components that comprise the soil exchange capacity. A significant decrease in organic matter with soil depth is evident. While percentage clay did not display a statistically significant decrease with depth, soil sampled from the 0-50 cm depths contained slightly more clay than soil from the 50-150 cm depths.

Exchangeable Sodium Percentage (ESP)

The three components of ESP, water soluble sodium, ammonium

acetate soluble sodium, and cation exchange capacity, displayed strong depth functions and as a result the ESP increased as distance below the surface increased. The processes of leaching alkali salts and of acidification by organic matter plus differences in parent material within a given sampling location were important factors in establishing this spatial pattern.

Plant Macronutrients

Both forms of nitrogen showed vertical pattern, although the direction was different. Ammonium was highest at the surface and consistently decreased with increasing depth. Soil ammonium is derived almost entirely from the decomposition of organic matter. Both organic matter and microbial activity are centered in the surface few cm of soil in semi-arid areas (Charley and Cowing 1968). The positively charged ammonium ion is generally held by clay particles and is not subject to translocation by water. Therefore, the concentration of ammonium is highest at the soil surface. Nitrifying bacteria convert ammonium to nitrate. This nitrate is either absorbed by plants and soil microorganisms or it is leached from the surface soil (Delwiche 1970). Thus, the concentration of soil nitrate is generally low and subject to loss by leaching. The high mobility of nitrate in the soil complicate patterns in its vertical distribution.

Plant available phosphorus was substantially higher in the 0-10 cm sample than in the subsurface soil samples. Organic matter and soil microorganisms, both of which are concentrated at the soil surface, significantly increase the concentration of available phosphorus (Brady 1974). As the

organic matter and population of microorganisms decreases with depth, the available phosphorus also decreases.

Plants absorb relatively large amounts of potassium and when plants die, this potassium is returned to the soil by way of organic matter decomposition. Thus, the soil surface generally contains more plant-available potassium than the subsoil, and this pattern was evident in the soils of the study area.

Water-soluble magnesium, calcium, and sulfate displayed a slight increase in concentration as soil depth increased. However, the differences were not statistically significant. As leaching continues to translocate these water-soluble constituents, differences may become more striking. The vertical distribution of potassium was irregular and the slight accumulation of this element at the soil surface may have been related to the release of potassium during organic matter decomposition. A similar irregular distribution of water-soluble potassium was also noted by Presant (1971).

Plant Micronutrients

Of the seven micronutrients analyzed, only manganese, zinc and chloride displayed significant changes with depth. The substantially higher concentration of manganese and zinc at the soil surface as compared to the subsoil indicated that these elements are associated with organic matter where they are probably held as chelated complexes. A general decrease in the concentration of manganese and zinc with depth was also found by Ravikovitch, Margolin, and Navrot (1961), Swaine (1960), and Presant (1971).

The increase in chloride with depth parallels that of electrical conductivity. The negatively charged chloride ion is necessary to balance the positively charged ions which electrical conductivity measures.

Organic Matter

Vertical gradients in organic matter content of soils has long been recognized. Above-ground plant material is eventually deposited at the soil surface where it is decomposed and incorporated into the soil. Vertical gradients in organic matter develop rapidly and are characteristic of essentially all soils. Subsurface organic matter is derived primarily from roots. Roots are substantially more numerous near the soil surface and thus contribute to the observed vertical pattern.

Trace Elements

Most of the trace element content of soil is bound in crystal lattice of the constituent rock-forming minerals. The proportion of such materials which undergo chemical and physical weathering is relatively minor and the amounts of trace elements available for pedological translocations is small. Thus, few changes in trace element concentration as depth from the surface increases can be ascribed to pedological factors. If vertical differentiation does develop, it is generally related to trace element changes in the parent material (Swaine and Mitchell 1960; Connor, et al 1976).

Few of the trace elements studied on Tract C-a and adjacent areas displayed consistent vertical patterns. Fluoride, selenium and lead showed consistent changes as depth increased, but only lead had statistically significant changes.

The accumulation of lead at or near the soil surface has been reported by several investigators (Rains 1975; Presant 1971). Apparently, lead absorbed by plants is converted into insoluble forms when plants are decomposed. This biological accumulation of lead is evident at the soil surface where above-ground plant biomass decomposes and in the near surface soil where the bulk of the root biomass is located. This appeared to be the case in the study area, although the differences in the lead concentration were small and of questionable biological significance.

The concentration of ammonium acetate soluble nickel was higher in the 10-50 cm depth than in the other depths sampled. A similar increase in subsurface nickel was also noted by Swaine and Mitchell (1960). The factors responsible for this slight but statistically significant increase in nickel are not known at the present time.

Background Radioactivity

Only one component of background radioactivity, potassium radioactivity, showed a statistically significant change with depth. Potassium radioactivity was higher in the surface sampling interval than in the three subsurface intervals. The same distribution was also observed for available potassium and for water-soluble potassium. Plant absorption and accumulation of potassium may have influenced the distribution of radioactive potassium.

Physical Properties

Although statistically significant differences were found in some physical traits, it is doubtful that the observed differences are biologically meaningful. Percentage sand increased with depth and percentage silt and clay decreased slightly with depth. This may reflect a more intensive physical and chemical soil weathering regime near the soil surface.

Soil Traits as Influenced by Vegetation

Vegetation plays an important role in the redistribution of soil constituents. Plants absorb soil constituents from a large area and concentrate them in a relatively small area, thus contributing to the vertical gradients in soil. Certain types of vegetation will impart different traits to the soil. Rooting pattern, life span, phenology, elemental composition, and other factors differ from one plant species to another and can significantly influence many soil traits. Comparison of prairie soils with forest soils is the classical example of the influence of different types of vegetation on soil traits (Jenny 1941).

Two approaches were employed in investigating the influence of vegetation on soil traits. One approach evaluates soil traits on the basis of dominant vegetation on the sampling site. The second approach looks as the influence of a single species, pinyon pine, on soil traits. Both approaches consider the soil traits of the 0-50 cm sampling depths. The 50-100 cm and 100-150 cm depths were far enough below the surface to be essentially unaffected by vegetation.

Soil Traits as Related to Dominant Vegetation

The soils of the study area were grouped on the basis of the dominant vegetation at the sampling site. Mean values of soil traits on the basis of dominant vegetation are presented in Table 4. Not all of the vegetative types found in the study area were included. A limited number of samples were taken on sites where aspen, Douglas fir, grasses, or riparian vegetation dominated. The number of soil samples collected on these sites was not sufficient to allow for meaningful comparisons.

The association of a particular type of vegetation with particular soil traits does not necessarily mean that the vegetation imparted these traits to the soil. The vegetation under study may have a competitive advantage on certain soils, and this does not involve any significant influence of the vegetation on soil traits. Factors such as differences in parent material, relief, microclimate, and time influence soil traits and may mask the influence of vegetation or erroneously imply vegetative influence.

Sagebrush. Big sagebrush, the most common plant species in the study area, was found on moderately alkaline, nonsaline, and nonsodic soils. The soluble salt electrical conductivity and the ESP were low relative to the 0-50 sampling depths for the entire study area (Table 3) and relative to the other species listed in Table 4. The concentration of plant nutrients showed no significant variation from the study area. However, the concentration of water-soluble nutrients was generally lower for the sagebrush soils than

TABLE 4

Soil Traits as Related to Dominant Vegetation

Dominant Species	pH in Water	pH in 0.01M $CaCl_2$	Soluble Salt Electrical Conductivity mmhos/cm (1)	Soluble Salt Electrical Conductivity mmhos/cm (2)	Sodium Water Soluble (milliequivalents/100 g)	Sodium NH_4 Acetate Soluble (milliequivalents/100 g)	Cation Exchange Capacity (milliequivalents/100 g)	Exchangeable Sodium Percentage
Sagebrush	8.3	7.7	0.34	1.7	0.36	1.36	39.3	2.5
Pinyon-Juniper	8.2	7.6	0.47	1.9	0.39	1.50	41.3	2.7
Shadscale	8.2	8.0	0.87	3.5	0.53	1.74	25.4	4.8
Mixed Brush	8.0	7.5	0.42	1.4	0.07	0.54	62.3	0.8
Rabbitbrush	8.3	7.9	0.74	2.4	0.43	0.86	34.0	1.3
Greasewood	9.0	8.3	2.96	12.3	5.02	9.36	26.6	16.3

Dominant Species	Ammonium ppm	Nitrate ppm	Phosphorus $NaHCO_3$ Extractable ppm	Potassium Available ppm	Water Soluble Magnesium ppm	Water Soluble Calcium ppm	Water Soluble Potassium ppm	Water Soluble Sulfate ppm	Water Soluble Boron ppm	DTPA Extractable Copper ppm	DTPA Extractable Manganese ppm	DTPA Extractable Iron ppm	DTPA Extractable Zinc ppm
Sagebrush	9.0	1.8	12.1	412.0	7.2	38.1	8.8	172.1	0.6	1.5	37.4	89.1	1.4
Pinyon-Juniper	10.4	2.0	17.1	311.9	9.2	44.5	8.4	154.4	0.7	1.5	42.1	111.8	1.5
Shadscale	11.8	3.6	6.3	152.5	30.6	225.0	7.1	818.4	0.6	2.9	21.5	77.2	1.2
Mixed Brush	13.8	3.5	11.2	660.0	5.9	47.8	13.5	133.4	0.6	2.2	51.3	161.5	2.0
Rabbitbrush	12.8	3.0	26.9	876.0	19.0	74.3	35.4	264.1	0.7	1.8	30.4	65.1	1.6
Greasewood	10.1	12.8	18.5	674.5	19.4	64.4	21.5	1073.3	0.8	2.2	36.6	147.2	1.8

Dominant Species	Molybdenum Anion Exchangeable ppm	Organic Matter %	Gypsum Requirement MEQ/100 g	Lime Requirement lb $CaCO_3$/acre	Total Phosphorus ppm	Total Arsenic ppm	Total Cadmium ppm	Total Chloride ppm	Total Chromium ppm	Total Cobalt ppm	Total Fluoride ppm	Total Mercury ppb
Sagebrush	0.3	2.8	0.3	0	558.4	8.1	0.5	838.4	46.0	8.1	463.2	16.5
Pinyon-Juniper	0.3	4.1	0.3	0	535.5	6.7	0.5	840.8	43.6	8.2	420.8	19.2
Shadscale	0.4	2.2	0.3	0	440.4	15.0	0.5	1058.3	34.6	6.8	646.7	32.5
Mixed Brush	0.4	6.8	0.9	0	607.1	11.3	0.5	691.7	45.1	8.7	506.7	18.8
Rabbitbrush	0.4	4.2	0.2	0	492.0	10.0	0.5	740.0	44.5	6.8	664.0	18.5
Greasewood	0.5	2.1	0.5	0	617.8	7.0	0.5	1100.0	47.5	8.4	551.0	21.5

Dominant Species	Total Antimony ppm	Total Vanadium ppm	Selenium Available ppb	NH_4 Acetate Extractable Nickel ppm	NH_4 Acetate Extractable Lead ppm	Background Radioactivity Uranium ppm	Background Radioactivity Equivalent Uranium ppm	Background Radioactivity Equivalent Thorium ppm	Background Radioactivity Potassium Radioactivity %	Background Radioactivity Radium226 Picocuries/g
Sagebrush	1.0	59.6	15.6	0.8	1.3	2.1	2.7	10.9	2.6	0.9
Pinyon-Juniper	1.1	55.4	14.8	0.9	1.5	2.2	2.5	11.1	2.5	0.9
Shadscale	1.0	62.9	16.7	1.3	2.3	2.3	2.4	8.3	2.1	0.8
Mixed Brush	1.0	68.3	14.2	1.0	1.1	2.1	2.9	10.9	2.8	0.9
Rabbitbrush	1.0	64.5	46.0	0.7	1.6	2.0	2.6	9.0	2.6	0.9
Greasewood	1.0	61.5	126.0	1.0	1.6	2.2	2.4	9.6	2.4	0.8

Dominant Species	Water-Holding Capacity, % (Dry Sample Wt. Basis) 1/3 Bar Suction	Water-Holding Capacity, % (Dry Sample Wt. Basis) 15 Bar Suction	Particle-Size Analysis, Wt. % Sand -2.0 +0.05 mm	Particle-Size Analysis, Wt. % Silt -0.05 +0.002 mm	Particle-Size Analysis, Wt. % Clay -0.002 mm	Textural Class
Sagebrush	24.4	12.3	37.9	47.3	14.8	Loam
Pinyon-Juniper	25.1	13.1	43.3	43.7	13.0	Loam
Shadscale	25.1	11.3	31.0	58.1	10.9	Silt loam
Mixed Brush	31.9	16.5	25.7	54.6	19.8	Silt loam
Rabbitbrush	30.9	14.6	27.6	56.7	15.7	Silt loam
Greasewood	24.1	10.5	38.8	51.2	10.1	Silt loam

(1) Sample to extract ratio: 1 to 2.

(2) Conductivity for a saturation extract based on 1 to 2 ratio conductivity data and the 1/3 bar water-holding capacity.

for the other vegetative types examined. Organic matter, trace elements, background radioactivity, and physical properties displayed no unusual values.

Pinyon-Juniper. The nonsaline, nonsodic, and moderately alkaline soils of the pinyon-juniper vegetation type showed no unusual traits relative to the surface and near surface soils of the study area. These soils were very similar in chemical traits to those associated with sagebrush. Pinyon-juniper soils contained the least amount of silt and the greatest amount of sand for the vegetative types studies. Both pinyon and juniper apparently have a competitive advantage on sandy, and frequently rocky, soils.

Shadscale. Soils of the shadscale vegetation type were nonsaline and nonsodic, but the soluble salt electrical conductivity and the ESP were relatively high when compared to the soils of other vegetative types. Fireman and Hayward (1952) found that the soil under shadscale was higher in ESP and in electrical conductivity than the soil outside of the influence of this shrub. Similar results were reported by Sharma and Tongway (1973) for another species of Atriplex. These results imply that shadscale redistributes (directly or indirectly) sodium and other salts. Shadscale soils were unusually low in extractable phosphorus and available potassium and unusually high in magnesium, calcium, and sulfate. Many of the trace elements, especially lead, nickel, mercury, and arsenic were slightly more concentrated in shadscale soils than in soils of other vegetative types. Areas dominated by shadscale were generally located on steep canyon slopes where soils were poorly developed and very shallow. Parent material has

strongly influenced the chemical traits of the shadscale soils and probably accounts for most of the differences noted.

Mixed Brush. These soils had the lowest pH, electrical conductivity, ESP, magnesium, and sulfate of those listed in Table 4. This suggests that leaching is more intense in this vegetative type than in the other types studied. Mixed brush was generally found on north-facing slopes in the higher areas of the study area. Such areas tend to be relatively moist and presumably more intensively leached. Extractable manganese, zinc, and iron were relatively high for these soils. Organic matter was also high and this may be related to the deciduous nature of many shrubs of the mixed brush type. The annual shedding of leaves may increase the soil organic matter over that found in areas dominated by vegetation that retains leaves. In addition, leaves of deciduous plants decompose faster than leaves from nondeciduous plants. These soils had the least amount of sand and the greatest amount of clay. This may indicate a slightly more intense chemical and physical weathering of soil.

Rabbitbrush. The degree of influence of rabbitbrush on soil traits appeared to be of the same low magnitude as indicated for sagebrush and pinyon-juniper. Extractable phosphorus and potassium were unusually high for these soils. Rabbitbrush generally dominated on bottomland soils where the sagebrush had been eliminated by burning. This burning may have increased the concentration of phosphorus and potassium (Uggla 1959). The other soil traits for rabbitbrush soils did not display unusual concentrations

of elements relative to the study area and to the other vegetative types studied.

Greasewood. This vegetative type appeared to occur on a distinct soil type. Soils where greasewood dominate are saline, sodic, and strongly alkaline (See Table 4). Fireman and Hayward (1952) found that pH, electrical conductivity, and ESP were higher under greasewood plants than in open areas free from the influence of greasewood. The authors found that greasewood leaves contained a high proportion of its anions in the form of organic acids. When the leaves decompose and various products released to the soil, calcium and magnesium are displaced on the soil exchange complex and replaced with sodium, thus increasing both pH and ESP. Nitrate and sulfate were two micronutrients that were unusually high for the area dominated by greasewood. The possibility of greasewood influencing the distribution of these macronutrients is intriguing, but only speculative at this point. Micronutrient and trace element concentrations in the area dominated by greasewood were similar to the concentrations in areas dominated by other forms of vegetation. However, selenium was the exception, and in the greasewood dominated area this element averaged 120 ppb as compared to 46 ppb for the 0-50 cm sampling depths of the entire study area. Greasewood is not listed as a plant that accumulates large amounts of selenium (Beath 1959). Ganje (1966) reported that areas which support an abundance of selenium-accumulating plants may have the surface soils enriched as plants decompose and release selenium to the surface soil. However, such selenium-accumulating plants were not observed in the greasewood areas or in other parts of the study area. A

reasonable explanation for the unusual concentration of selenium in greasewood dominated soils cannot be given at this time. Background radioactivity and physical traits were in the range expected, although greasewood soils had the least amount of clay for the vegetative types studied.

Soil Traits as Influenced by Pinyon Pine

In order to quantitatively evaluate the influence of vegetation on soil traits, other factors influencing soil traits must be kept constant or allowed to vary within a range that does not significantly influence the traits being measured. Equations developed by Jenny (1958, 1961) and Major (1951) provided a basis for development of a conceptual model for studying the effect of vegetation of soil traits. The model stated that any ecosystem property (l) was functionally related to climate (cl), the biotic factor (o), topography (r), the initial state of the soil system (i), and time (t). For this study, this functional factoral relationship was expressed as follows:

$$1 = f(0_{\text{species}})\ cl, r, i, t.$$

The variable l represented the chemical traits of the soil and 0_{species} represented the influence of pinyon pine (pine ecosystem) and the influence of a sparse grass-forb ecosystem on soil traits. Variables of cl, r, i, and t were kept constant.

Soil samples were taken under two large, and presumable old, pinyon pines (sampling sites 99 and 101). The soil samples were taken approximately 20 cm from the bole and were within the canopy projection of the tree. The litter averaged 15 cm deep. Soil samples were also taken approximately

15 m from the first set of samples (sampling sites 100 and 102). These open areas contained scattered grasses and forbs, and percentage cover was about 30. These sites were free of visible plant litter.

The above sites were chosen to maximize and to minimize the biotic influence on soil properties while keeping all other influences on soil traits constant. Table 5 presents the results. No statistical analysis was attempted due to the small sample size. In interpreting the results, one must keep in mind the limited scope of this study. The differences found may be representative of a wide area or may be confined to the area just described. Further sampling is needed to determine how representative these values are.

pH. Surface and subsurface pH values (in water) were identical for both sites.

Soluble Salt Electrical Conductivity. The surface soil under pinyon pine averaged 11.9 mmhos/cm while the surface soil in the open area averaged 1.6 mmhos/cm. Subsurface differences were also obvious but not as striking. With a dense crown and a thick layer of litter on top of the soil, a significant portion of the precipitation is intercepted and does not reach the soil. Thus, leaching under the pinyon pine was substantially less than in the open grass-forb ecosystem. As mentioned before, leaching is a significant factor in the soil distribution of soluble salts. Other factors may be involved. Presumable, considerably more litter is produced in the pine ecosystem than in the grass-forb ecosystem. Litter contains water soluble salts, and the release of these salts during decomposition may increase the salinity of the soil and contribute to the observed pattern.

TABLE 5

Soil Traits as Influenced by Pinyon Pine

Ecosystem	Depth, cm From	Depth, cm To	pH in Water	pH in 0.01M $CaCl_2$	Soluble Salt Electrical Conductivity mmhos/cm (1)	Soluble Salt Electrical Conductivity mmhos/cm (2)	Sodium Water Soluble (milliequivalents/100 g)	Sodium NH_4 Acetate Soluble (milliequivalents/100 g)	Cation Exchange Capacity (milliequivalents/100 g)	Exchangeable Sodium Percentage
Pinyon Pine	0	10	8.0	7.8	2.82	11.9	1.61	2.40	38.4	2.1
Pinyon Pine	10	50	8.3	8.0	1.44	6.7	1.43	3.40	34.3	5.7
Grass-Forb	0	10	8.0	7.3	0.35	1.6	0.29	1.90	34.6	4.7
Grass-Forb	10	50	8.3	7.8	0.44	1.7	0.33	0.70	40.7	<1.0

Ecosystem	Depth, cm From	Depth, cm To	Ammonium ppm	Nitrate ppm	Phosphorus $NaHCO_3$ Extractable ppm	Potassium Available ppm	Water Soluble Magnesium ppm	Water Soluble Calcium ppm	Water Soluble Potassium ppm	Water Soluble Sulfate ppm	Water Soluble Boron ppm	DTPA Extractable Copper ppm	DTPA Extractable Manganese ppm	DTPA Extractable Iron ppm	DTPA Extractable Zinc ppm
Pinyon Pine	0	10	17.6	8.8	143	1140	68.9	171.9	61.5	1082	1.2	1.2	77	99	3.2
Pinyon Pine	10	50	14.9	1.7	32	580	40.3	120.0	27.3	585	1.2	0.8	40	58	0.9
Grass-Forb	0	10	15.3	0.8	10	330	6.8	27.7	9.2	141	0.7	1.1	50	73	1.7
Grass-Forb	10	50	8.3	1.3	6	200	8.0	38.9	4.4	107	0.6	1.2	41	95	1.3

Ecosystem	Depth, cm From	Depth, cm To	Molybdenum Anion Exchangeable ppm	Organic Matter %	Gypsum Requirement MEQ/100 g	Lime Requirement lb $CaCO_3$/acre	Total Phosphorus ppm	Total Arsenic ppm	Total Cadmium ppm	Total Chloride ppm	Total Chromium ppm	Total Cobalt ppm	Total Fluoride ppm	Total Mercury ppb
Pinyon Pine	0	10	1.2	11.9	<0.2	0	718	8	<0.5	1450	30	10	310	15
Pinyon Pine	10	50	0.5	3.2	<0.2	0	498	5	<0.5	1300	33	9	330	13
Grass-Forb	0	10	0.3	2.7	<0.2	0	516	5	<0.5	950	35	8	340	15
Grass-Forb	10	50	0.3	2.9	<0.2	0	527	8	<0.5	1100	30	8	340	18

Ecosystem	Depth, cm From	Depth, cm To	Total Antimony ppm	Total Vanadium ppm	Selenium Available ppb	NH_4 Acetate Extractable Nickel ppm	NH_4 Acetate Extractable Lead ppm	Background Radioactivity Uranium ppm	Background Radioactivity Equivalent Uranium ppm	Background Radioactivity Equivalent Thorium ppm	Background Radioactivity Potassium Radioactivity %	Background Radioactivity Radium^{226} Picocuries/g
Pinyon Pine	0	10	<1	40	20	1.6	2.5	<2	3	12	2.6	1.0
Pinyon Pine	10	50	<1	50	10	1.1	1.7	<2	3	12	3.1	1.0
Grass-Forb	0	10	<1	50	10	0.8	1.7	<2	3	16	2.5	1.0
Grass-Forb	10	50	<1	45	10	1.2	2.2	<2	3	14	2.5	1.0

Ecosystem	Depth, cm From	Depth, cm To	Water-Holding Capacity, % (Dry Sample Wt. Basis) 1/3 Bar Suction	Water-Holding Capacity, % (Dry Sample Wt. Basis) 15 Bar Suction	Particle-Size Analysis, Wt. % Sand -2.0 +0.05 mm	Particle-Size Analysis, Wt. % Silt -0.05 +0.002 mm	Particle-Size Analysis, Wt. % Clay -0.002 mm	Textural Class
Pinyon Pine	0	10	23.6	17.9	54.0	40.0	6.0	Sandy loam
Pinyon Pine	10	50	21.6	12.0	42.0	44.0	14.0	Loam
Grass-Forb	0	10	22.4	11.8	38.5	49.5	12.0	Loam
Grass-Forb	10	50	26.6	14.8	37.0	48.5	14.5	Loam

(1) Sample to extract ratio: 1 to 2.

(2) Conductivity for a saturation extract based on 1 to 2 ratio conductivity data and the 1/3 bar water-holding capacity.

Cation Exchange Capacity. The cation exchange capacity varied little between the two ecosystems and this appeared to be the result of compensating factors. The organic matter content in the 0-10 cm interval of the pine ecosystem was relatively high, but percentage clay was low. For the remaining three samples, organic matter and clay had very similar values.

Exchangeable Sodium Percentage. The ESP showed no significant variation between the two ecosystems.

Plant Macronutrients. The pine ecosystem contained more nitrogen, extractable phosphorus, available potassium, and water-soluble magnesium, calcium, potassium, and sulfate than the grass-forb ecosystem. This rather substantial difference in the concentration of macronutrients probably reflects increased nutrient cycling and less leaching in the pinyon pine ecosystem as compared to the grass-forb ecosystem.

Plant Micronutrients. There were no striking differences in the micronutrient concentration between ecosystems. The surface soil of the pine ecosystem contained slightly more manganese, iron, zinc, and molybdenum than the grass-forb system and this may be related to the above-mentioned nutrient cycling process.

Organic Matter. The surface soil of the pine ecosystem, overlain by a deep layer of litter, contained significantly more organic matter than the surface sample of the grass-forb ecosystem. Both subsurface samples had similar amounts of organic matter and this suggests that most of the organic matter in the pine ecosystem originated from litter rather than from roots.

Trace Elements. The vegetative influence on trace element distribution appeared minor. No striking differences between the two ecosystems were noted. Lead, nickel, selenium, and cobalt were slightly higher in the surface soil of the pine ecosystem than in the grass-forb ecosystem. However, these slight differences may not be related to vegetative factors.

Physical Traits. Changing the physical traits of soil requires considerable time and the life span of a given plant is not long enough to directly affect the physical traits of soil. In some cases, plants may indirectly change physical traits of the soil by collecting aeolian material beneath their canopies (Muller 1953). This may have been the case in this study as the pine ecosystem contained a higher percentage sand than the open grass-forb ecosystem.

SOIL TRAITS OF TRACT C-a

Of the 312 soil samples taken by specific depth, 130 of these were taken within the boundaries of Tract C-a (see Figure 1). The chemical and physical properties of these samples are presented in Table 6. Following is a discussion of how these soils differ from those of the entire study area.

Soil traits of pH, soluble salt electrical conductivity, and ESP are essentially the same in Tract C-a as in the study area. The degree to which these properties may restrict plant growth is the same as that previously discussed.

With few exceptions, the concentration of plant macronutrients was of the same magnitude in both areas. Nitrate and available potassium were

TABLE 6

Chemical and Physical Traits of Tract C-a(1)

Parameter	pH in Water	pH in 0.01M $CaCl_2$	Soluble Salt Electrical Conductivity mmhos/cm (2)	Soluble Salt Electrical Conductivity mmhos/cm (3)	Sodium Water Soluble (milliequivalents/100 g)	Sodium NH_4 Acetate Soluble (milliequivalents/100 g)	Cation Exchange Capacity (milliequivalents/100 g)	Exchangeable Sodium Percentage
Mean	8.3	7.9	0.86	3.2	1.09	2.82	34.2	5.1
Range	7.3-9.8	6.9-9.2	0.18-11.50	0.6-59.0	0.07-19.48	0.25-30.1	15.4-63.8	0.1-53.5
Standard Deviation	0.5	0.4	1.40	6.2	2.5	4.1	10.5	9.5

Parameter	Ammonium	Nitrate	Phosphorus $NaHCO_3$ Extractable	Potassium Available	Water Soluble					DTPA Extractable			
	ppm	ppm	ppm	ppm	Magnesium ppm	Calcium ppm	Potassium ppm	Sulfate ppm	Boron ppm	Copper ppm	Manganese ppm	Iron ppm	Zinc ppm
Mean	9.0	10.5	12.6	262.1	14.5	59.6	10.0	302.8	0.7	2.1	30.2	81.0	1.4
Range	0.4-27.9	<0.1-420.0	1.0-125.0	80.0-1190.0	0.4-319.7	3.6-679.0	1.1-83.5	5.0-4158.0	0.5-1.9	0.5-13.6	6.0-120.0	12.0-210.0	0.4-4.3
Standard Deviation	5.3	43.2	13.1	202.0	33.0	105.7	13.8	624.0	0.2	1.6	20.9	46.4	0.7

Parameter	Molybdenum Anion Exchangeable	Organic Matter	Gypsum Requirement	Lime Requirement	Total							
	ppm	%	MEQ/100 g	lb $CaCO_3$/ acre	Phosphorus ppm	Arsenic ppm	Cadmium ppm	Chloride ppm	Chromium ppm	Cobalt ppm	Fluoride ppm	Mercury ppb
Mean	0.3	3.1	0.3	0	450.1	10.0	0.5	1001.8	44.0	7.0	596.5	24.0
Range	0.1-1.3	0.1-16.8	0.2-2.2	0	201.0-840.0	5.0-40.0	<0.5-0.5	400.0-2500.0	20.0-65.0	1.0-35.0	290.0-1150	10-110
Standard Deviation	0.2	2.2	0.4	0	135.9	7.2	<0.01	338.1	10.0	3.2	188.7	15.1

Parameter	Total		Selenium Available	NH_4 Acetate Extractable		Background Radioactivity				
	Antimony ppm	Vanadium ppm	ppb	Nickel ppm	Lead ppm	Uranium ppm	Equivalent Uranium ppm	Equivalent Thorium ppm	Potassium Radioactivity %	Radium226 Picocuries/ g
Mean	1.0	57.7	34.1	0.7	1.6	2.3	2.9	9.4	2.4	1.0
Range	1.0-3.0	30.0-110.0	10-500	0.3-2.4	0.7-4.0	<2.0-5.0	1.0-8.0	3.0-17.0	0.5-4.7	0.5-2.5
Standard Deviation	0.3	13.6	60.3	0.4	0.5	0.7	1.2	3.3	0.6	0.4

Parameter	Water-Holding Capacity, % (Dry Sample Wt. Basis)		Particle-Size Analysis, Wt. %			Textural Class
	1/3 Bar Suction	15 Bar Suction	Sand -2.0 +0.05 mm	Silt -0.05 +0.002 mm	Clay -0.002 mm	
Mean	26.9	13.0	36.5	50.3	13.2	Loam
Range	14.9-50.9	7.0-22.9	7.0-73.0	22.0-77.0	2.5-25.0	
Standard Deviation	6.9	3.3	15.6	12.7	5.1	

(1) n = 130.

(2) Sample to extract ratio: 1 to 2.

(3) Conductivity for a saturation extract based on 1 to 2 ratio conductivity data and the 1/3 bar water-holding capacity.

exceptions. In Tract C-a, nitrate averaged 10.5 ppm as compared to 6.3 for the study area. Of the 11 samples containing more than 30 ppm nitrate, 8 of these were in Tract C-a. These samples were largely responsible for increasing the average nitrate concentration over that found in the study area. The concentration of available potassium in Tract C-a averaged 262 ppm, a value 123 ppm less than the study area. These differences in macronutrient concentration are not unusual considering the heterogeneous nature of the soils found in the study area.

Micronutrients showed no significant variation when Tract C-a was compared to the study area. This lack of variation was also evident in the comparisons of trace elements. However, available selenium was an exception and its concentration was substantially lower in Tract C-a (averaging 34 ppb) than in the study area (averaging 56 ppb). None of the sampling sites containing abnormally high amounts of selenium were located in Tract C-a.

Background radioactivity and the physical traits of texture and water-holding capacity showed no significant change from the study area to Tract C-a. On the average, soils in Tract C-a contained slightly more silt and correspondingly less sand than the study area. However, differences of this magnitude are not thought to be biologically significant.

SOIL TRAITS OF MESA 84

A total of 37 samples were collected in a relatively flat area known as 84 Mesa. This area, approximately 10 square miles in area, is located three miles northeast of Tract C-a and may serve as a site for the disposal

of spent shale. The following discussion relates these soils (Table 7) to those of the study area.

Soils of the study area had an electrical conductivity of 3.5 mmhos/cm while that portion of the study area designated as 84 Mesa had soils which averaged 5.7 mmhos/cm of electrical conductivity. Of the 15 soil samples classified as highly saline for the study area, 5 of these samples occurred in 84 Mesa Either the 50-100 or the 100-150 cm sampling depth of sites 47, 48, 50, 51, and 53 were highly saline. As previously mentioned, these highly saline subsurface materials had no apparent effect on plant growth.

Differences in pH, ESP, and plant macronutrients were slight between 84 Mesa and the study area. Water soluble salts including sodium, calcium, and magnesium were slightly more concentrated in 84 Mesa than in the study area. This increased soluble salt concentration reflected the higher electrical conductivity for the soils of 84 Mesa. The sulfate concentration on 84 Mesa (691.1 ppm) was slightly over twice the average concentration of the study area. The reasons for the variation in sulfate are not clear, but there appears to be no biological implications.

The micronutrient and trace element concentrations of both areas were not substantially different, with the exception of selenium. Selenium on 84 Mesa averaged 19 ppb compared with 56 ppb for the study area. The absence of samples with more than 1000 ppb selenium in 84 Mesa was responsible for the difference.

TABLE 7

Chemical and Physical Traits of the Disposal Area on Mesa 84[1,2]

Parameter	pH in Water	pH in 0.01M $CaCl_2$	Soluble Salt Electrical Conductivity mmhos/cm (3)	Soluble Salt Electrical Conductivity mmhos/cm (4)	Sodium Water Soluble	Sodium NH_4 Acetate Soluble	Cation Exchange Capacity	Exchangeable Sodium Percentage
					(milliequivalents/100 g)			
Mean	8.8	7.9	1.33	5.7	1.83	4.39	36.9	6.9
Range	8.1-9.9	7.1-8.7	0.12-7.80	0.5-39.0	0.04-7.64	0.38-14.80	18.2-53.5	0.9-35.9
Standard Deviation	0.4	0.3	2.1	9.4	2.4	4.2	8.0	8.2

					Water Soluble					DTPA Extractable			
Parameter	Ammonium ppm	Nitrate ppm	Phosphorus $NaHCO_3$ Extractable ppm	Potassium Available ppm	Magnesium ppm	Calcium ppm	Potassium ppm	Sulfate ppm	Boron ppm	Copper ppm	Manganese ppm	Iron ppm	Zinc ppm
Mean	7.2	4.6	10.7	378.6	23.3	88.5	9.4	691.1	0.5	1.4	29.8	112.9	1.3
Range	2.6-11.9	<0.1-83.6	3.0-25.0	160.0-960.0	1.8-156.8	4.6-536.0	1.4-34.4	70-2750	0.5-1.2	0.5-2.8	16-48	38-272	0.8-2.4
Standard Deviation	2.5	15.0	6.5	190.6	38.2	133.4	7.6	825.8	0.1	0.5	1.0	56.3	0.4

					Total							
Parameter	Molybdenum Anion Exchangeable ppm	Organic Matter %	Gypsum Requirement MEQ/100 g	Lime Requirement lb $CaCO_3$/acre	Phosphorus ppm	Arsenic ppm	Cadmium ppm	Chloride ppm	Chromium ppm	Cobalt ppm	Fluoride ppm	Mercury ppb
Mean	0.27	1.6	0.3	0	645.8	6.8	<0.5	754.1	47.6	9.6	398.6	12.7
Range	0.1-0.6	0.2-6.7	0.2-3.0	0	95-1549	5-20	0	400-1500	25-65	8-13	240-800	10-40
Standard Deviation	0.2	1.2	0.5	0	340.2	3.2	0	290.2	9.0	1.7	102.7	6.0

	Total			NH_4 Acetate Extractable		Background Radioactivity				
Parameter	Antimony ppm	Vanadium ppm	Selenium Available ppb	Nickel ppm	Lead ppm	Uranium ppm	Equivalent Uranium ppm	Equivalent Thorium ppm	Potassium Radioactivity %	$Radium^{226}$ Picocuries/g
Mean	1.0	63.9	18.6	0.9	1.0	2.2	2.8	11.8	2.6	1.0
Range	1.0-1.0	30-90	10-50	0.5-2.0	0.6-1.5	2-4	1-7	6-24	1.2-3.9	0.5-2.5
Standard Deviation	0	11.7	10.6	0.3	0.2	0.5	1.1	3.3	0.7	0.4

	Water-Holding Capacity, % (Dry Sample Wt. Basis)		Particle-Size Analysis, Wt. %			
Parameter	1/3 Bar Suction	15 Bar Suction	Sand -2.0 +0.05 mm	Silt -0.05 +0.002 mm	Clay -0.002 mm	Textural Class
Mean	23.2	10.9	40.4	42.9	16.7	Loam
Range	13.5-34.5	6.4-15.3	17.5-68.0	19.0-68.0	9.0-31.0	
Standard Deviation	4.7	2.2	14.1	12.5	5.7	

(1) n = 39.

(2) Mesa 84 includes Soil Sampling Sites 47-56, 58, and 59.

(3) Sample to extract ratio: 1 to 2.

(4) Conductivity for a saturation extract based on 1 to 2 ratio conductivity data and the 1/3 bar water-holding capacity.

Background radioactivity and the physical traits of water-holding capacity and texture were very similar for both areas. Soils in 84 Mesa contained slightly more clay and less silt than the study area, and this is probably related to the soil types that dominate 84 Mesa.

SOIL SERIES OF THE STUDY AREA

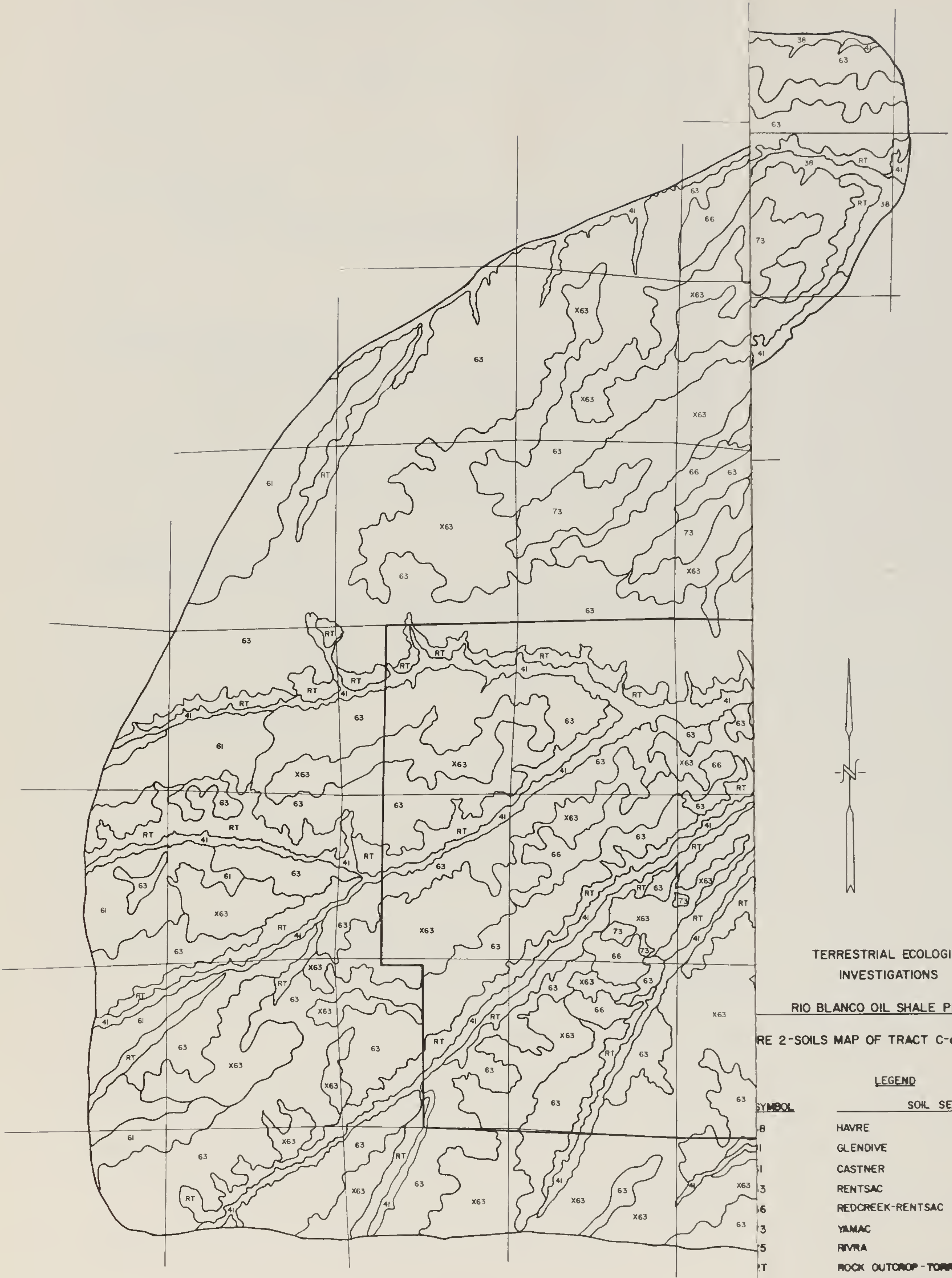
Nine soil series have been identified within the study area. The extent of each series was mapped. At a representative point within each series, a pit was dug and the soil profile described and sampled.

The Soil Map

The soil map for Tract C-a and adjacent areas is presented in Figure 2. A preliminary map was first made using recent aerial photographs and the soil map prepared by the Soil Conservation Service. This map was then refined on the basis of field reconnaissance and soil sampling.

The soil map implies that different soil series occur in well-defined units. However, this is not the case and the soil map is an abstraction from the actual field situation. Soil series do not occur in distinct units but one series grades into another series with no sharp demarkation between the two series. Soil mapping requires drawing lines between series, but such lines do not exist in the field.

Within any given series outlines in Figure 2, small areas of other soil series generally exist within the boundary. These inclusions are too small to map. The inclusions likely to be found within a given series are listed below. In some cases, two different soil series exist in a mosiac



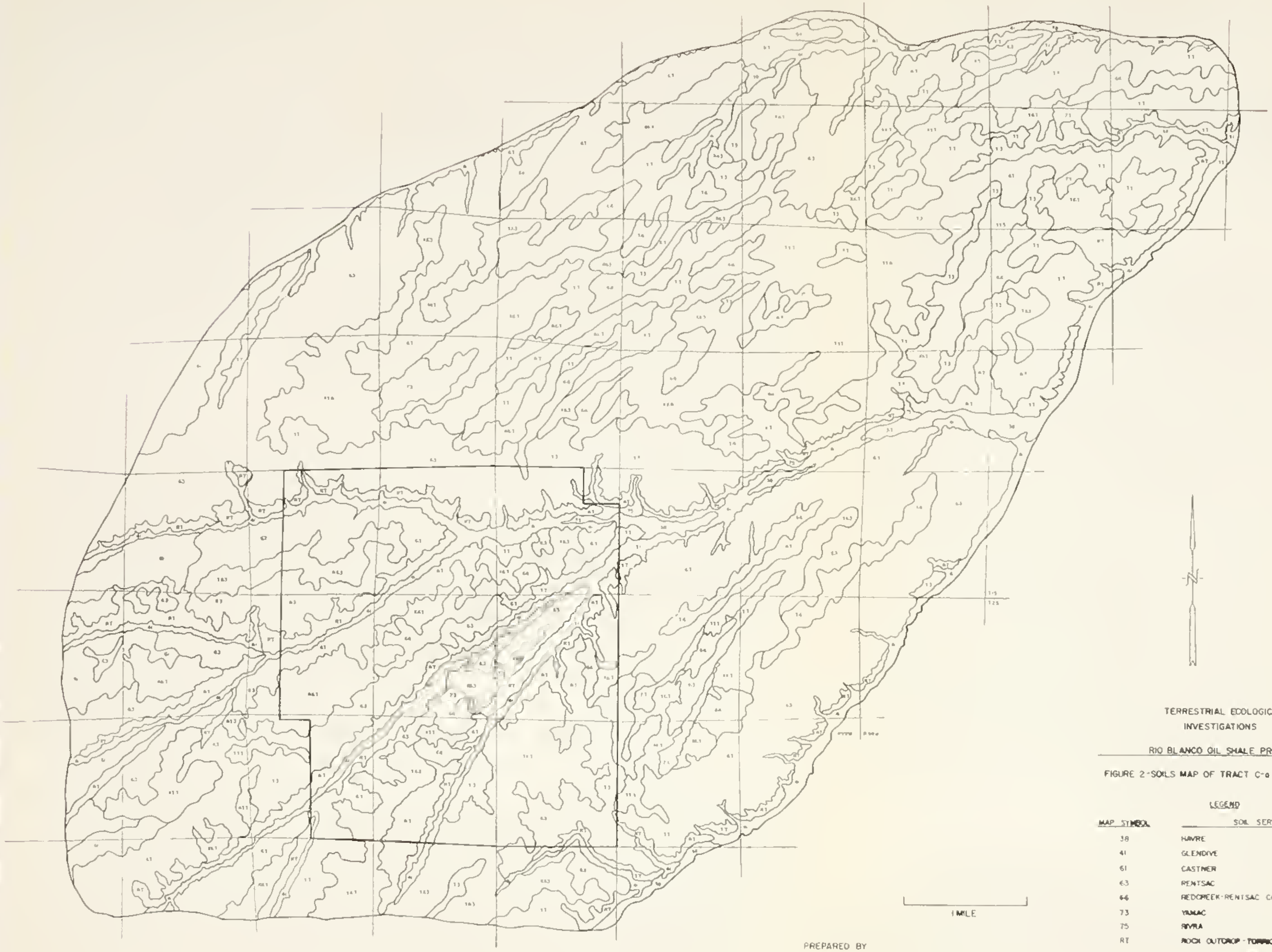
TERRESTRIAL ECOLOGICAL
INVESTIGATIONS

RIO BLANCO OIL SHALE PROJECT

RE 2-SOILS MAP OF TRACT C-o AND VICINITY

LEGEND

SYMBOL	SOIL SERIES
8	HAVRE
1	GLENDIVE
1	CASTNER
3	RENTSAC
6	REDCREEK-RENTSAC COMPLEX
3	YAMAC
5	RIVRA
T	ROCK OUTCROP-TORRIORTHENT COMPLEX
3	RENTSAC-PICEANCE COMPLEX



TERRESTRIAL ECOLOGICAL
INVESTIGATIONS

RIO BLANCO OIL SHALE PROJECT

FIGURE 2 - SOILS MAP OF TRACT C-a AND VICINITY

LEGEND

MAP SYMBOL	SOIL SERIES
38	HAVRE
41	GLENDIVE
61	CASTNER
63	RENTSAC
64	REDCREEK - RENTSAC COMPLEX
73	YAMAC
75	RIVRA
RT	ROCK OUTCROP - TORRIORTHENT COMPLEX
163	RENTSAC - PICEANCE COMPLEX

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and cannot be separated into individual series. The term "complex" is given to such areas. Following is a discussion of the mapping units shown in Figure 2.

Havre Series (38)

Small areas of the Glendive series may be included in this mapping unit.

Glendive Series (41)

In areas that are nearly level, small areas of the Havre series may be found. In steeper areas near the upstream boundary of the Glendive series small areas of the Rivra series may be included.

Castner Series (61)

Small inclusions of the Rentsac series and of the Torriorthent series may be found within the Castner series.

Rentsac Series (63)

In areas where the slope exceeds approximately 35%, small areas of the Torriorthent series may be found. Where the slope is less than 15%, small areas of the Redcreek series may be included in this mapping unit.

Rentsac-Piceance Complex (X63)

The Rentsac series makes up about 50% of this mapping unit and the Piceance series comprises approximately 40%. The remaining 10% consists of the Rock Outcrop-Torriorthent complex.

Redcreek-Rentsac Complex (66)

The Redcreek series makes up approximately 50% of this mapping unit, the Rentsac series makes up about 40%, and the remaining 10%

consists of the Rock Outcrop-Torriorthent complex, the Yamac series, and the Piceance series.

Yamac Series (73)

Small areas of the Piceance series and of the Rentsac series are found within the boundaries of the Yamac series.

Rivra Series (75)

Small areas of the Glendive series may be included in this mapping unit, especially where the slope is less than 5%.

Rock Outcrop-Torriorthent Complex (RT)

Approximately 45% of this mapping unit consists of rock outcrops occurring as horizontal sandstone cliffs and as platy shale outcrops. These outcrops are generally found along the major canyons disecting the study area. Vegetation is very sparse on these strongly sloping outcrops. An unnamed Torriorthent occupies about 40% of the area and the remainder consists of the Rentsac series.

Soil Profile Descriptions

With the aid of personnel from the Soil Conservation Service, a representative pedon was carefully selected for each soil series mapped. These pedons were described using standard Soil Conservation Service methods and terminology. A sample was taken of each soil horizon and analyzed in the laboratory using the methods previously described. The results of this investigation follow.

Havre Series

The Havre Series consists of deep, well drained soils that have formed in calcareous mixed alluvium. Such soils are found in valleys and on floodplains; slope ranges from 0 to 8%.

The surface of A horizon ranges in texture from sandy loam to silty clay loam. Color and depth vary widely, but generally the A horizon is brown and 16 cm deep. The subsurface layer consists of stratified loam, clay loam, and sandy loam material approximately 60 cm thick. These soils are commonly underlain by contrasting materials or bedrock. Fine filaments or threads of line may be present throughout part of the subsoil. Reaction ranges from mildly alkaline near the surface to strongly alkaline in sections of the subsoil. Layers of buried topsoil are commonly found in the subsurface layers.

Water permeability is moderate. Effective rooting depth is 150 cm or greater. The available water capacity is high, and the organic matter content in the surface layer is medium. Surface runoff is slow and the erosion hazard is moderate.

Vegetation on the soils in the Havre Series is quite variable. Some areas are covered by a dense ryegrass sod, while other areas are dominated by big sagebrush. In areas that have been burned, basin wildrye, tall rabbitbrush, or greasewood dominate. These soils are used for livestock grazing, wildlife habitat, and irrigated pasture.

A pedon considered typical of the Havre Series was located in the SE$\frac{1}{4}$, NW$\frac{1}{4}$, Section 35, T1S, R99W, and was described as follows:

A11--0 to 11 cm; grayish brown (10YR 5/2) silt loam, very dark grayish brown (10YR 3/2) when moist; moderate medium subangular blocky parting to moderate fine granular structure; soft, very friable, slightly sticky and slightly plastic; very abundant medium to very fine roots; slightly calcareous, moderately alkaline; clear smooth boundary.

A12--11 to 20 cm; grayish brown (10YR 5/2)silt loam, very dark grayish brown (10YR 3/2) when moist; moderate medium subangular blocky structure; soft, very friable, slightly sticky and slightly plastic, abundant medium to very fine roots; slightly calcareous, moderately alkaline; clear smooth boundary.

C1 -- 20 to 37 cm; weak red (2.5 YR 5/2) silt loam, dark grayish brown (10YR 4/2) when moist; moderate medium subangular blocky structure; slightly hard, friable, slightly sticky and slightly plastic; abundant medium to very fine roots; strongly calcareous, moderately alkaline; clear wavy boundary.

C2 -- 37 to 70 cm; light brownish gray (10 YR 6/2) silt loam, dark grayish brown (10 YR 4/2) when moist; massive; slightly hard, friable, sticky and plastic; common medium and fine roots; strongly calcareous, moderately alkaline; clear wavy boundary.

C3 -- 70 to 86 cm; light gray (10 YR 7/2) silt loam, grayish brown (10 YR 5/2) when moist; massive; slightly hard, friable, sticky

and plastic; common medium and fine roots; strongly calcareous, strongly alkaline; abrupt smooth boundary;

A 1b--86 to 117 cm; gray (10 YR 6/1) silty clay loam, dark gray (10 YR 4/1) when moist; massive; slightly hard, friable, sticky and plastic: common fine roots; slightly calcareous, strongly alkaline; clear wavy boundary.

C 1b--117 cm; light gray (10 YR 7/2) silt loam, dark brown (10 YR 4/3) when moist; massive; slightly hard, friable, sticky and plastic; common fine roots; strongly calcareous, moderately alkaline.

The chemical and physical properties of these horizons are given in Table 8. All horizons were nonsaline and nonsodic. Generally, ample amounts of macro- and micronutrients are available. The concentration of nitrogen is somewhat low and may restrict plant growth. However, as organic matter decomposes nitrogen is made available for plant absorption. This process of nitrogen release and absorption keeps the soil nitrogen level low and suggests nitrogen deficiencies when none exist. Percentage organic matter shows a consistent decrease with depth, except for a slight increase when the buried A horizon is encountered. The concentration of trace elements are within the range considered normal for surface soils and are close to the average values for the study area (Table 2). Physical properties show the expected increase in bulk density as depth increases. These soil horizons have the ability to retain substantial amounts of water and are fine

textured. Mahmoud (1977) also determined the chemical traits of the Havre series and found values of the same magnitude as presented in Table 8.

TABLE 8

Chemical and Physical Traits of a Havre Profile

Horizon	Depth, cm From	Depth, cm To	pH in Water	pH in 0.01M $CaCl_2$	Soluble Salt Electrical Conductivity mmhos/cm (1)	Soluble Salt Electrical Conductivity mmhos/cm (2)	Sodium Water Soluble (milliequivalents/100 g)	Sodium NH_4 Acetate Soluble (milliequivalents/100 g)	Cation Exchange Capacity (milliequivalents/100 g)	Exchangeable Sodium Percentage
A11	0	11	8.4	7.8	0.51	1.5	0.35	0.60	46.5	0.5
A12	11	20	8.3	7.8	0.46	1.4	0.25	0.70	46.1	1.0
C1	20	37	8.2	8.0	0.43	1.4	0.28	0.60	46.3	0.7
C2	37	70	8.4	8.0	0.43	1.4	0.25	1.00	36.1	2.1
C3	70	86	8.5	8.0	0.54	1.4	0.28	1.50	37.5	3.3
A1b	86	117	8.5	7.9	0.40	1.1	0.22	0.60	42.1	0.9
C1b	117	137	8.4	7.9	0.42	1.3	0.25	1.40	29.1	4.0

Horizon	Depth, cm From	Depth, cm To	Ammonium ppm	Nitrate ppm	Phosphorus $NaHCO_3$ Extractable ppm	Potassium Available ppm	Water Soluble Magnesium ppm	Water Soluble Calcium ppm	Water Soluble Potassium ppm	Water Soluble Sulfate ppm	Water Soluble Boron ppm	DTPA Extractable Copper ppm	DTPA Extractable Manganese ppm	DTPA Extractable Iron ppm	DTPA Extractable Zinc ppm
A11	0	11	2.0	2.9	35	1400	10.6	45.7	54.5	436	1.1	2.2	72	120	3.8
A12	11	20	10.6	3.6	16	1300	8.7	45.0	50.1	436	1.2	2.2	58	56	1.4
C1	20	37	22.6	2.3	27	1300	17.5	31.4	23.0	192	0.8	2.0	56	136	1.6
C2	37	70	24.6	2.6	8	720	14.5	37.9	20.0	179	0.9	2.6	25	122	0.8
C3	70	86	7.3	0.6	6	795	14.2	48.6	50.1	294	1.2	3.2	21	154	1.0
A1b	86	117	12.6	0.5	6	695	21.4	27.2	15.0	266	1.3	4.2	16	60	0.8
C1b	117	137	9.3	0.1	7	515	22.3	22.9	17.5	226	0.9	3.4	14	64	0.6

Horizon	Depth, cm From	Depth, cm To	Molybdenum Anion Exchangeable ppm	Organic Matter %	Gypsum Requirement MEQ/100 g	Lime Requirement lb $CaCO_3$ per Acre	Total Phosphorus ppm	Total Arsenic ppm	Total Cadmium ppm	Total Chloride ppm	Total Chromium ppm	Total Cobalt ppm	Total Fluoride ppm	Total Mercury ppb
A11	0	11	0.5	7.29	<0.2	0	697	5	<0.5	900	40	9	620	25
A12	11	20	0.6	6.58	<0.2	0	735	10	<0.5	1600	35	9	560	25
C1	20	37	0.8	5.42	<0.2	0	729	20	<0.5	1300	35	9	560	25
C2	37	70	0.5	2.16	<0.2	0	607	10	<0.5	800	40	6	620	20
C3	70	86	0.6	1.82	<0.2	0	565	10	<0.5	700	35	6	560	15
A1b	86	117	0.7	3.10	0.3	0	607	5	<0.5	800	40	6	720	15
C1b	117	137	0.5	1.45	<0.2	0	688	10	<0.5	800	40	9	600	15

Horizon	Depth, cm From	Depth, cm To	Total Antimony ppm	Total Vanadium ppm	Selenium Available ppb	NH_4 Acetate Extractable Nickel ppm	NH_4 Acetate Extractable Lead ppm	Uranium ppm
A11	0	11	<1	80	40	1.2	2.0	<2.0
A12	11	20	<1	70	40	1.0	1.8	<2.0
C1	20	37	<1	70	40	1.2	2.0	<2.0
C2	37	70	<1	70	50	1.2	2.0	<2.0
C3	70	86	<1	80	40	1.0	1.8	<2.0
A1b	86	117	<1	80	50	1.2	1.8	<2.0
C1b	117	137	<1	70	20	1.0	1.6	<2.0

Horizon	Depth, cm From	Depth, cm To	Bulk Density g/cm^3	Water-Holding Capacity, % (Dry Sample Wt. Basis) 1/10 Bar Suction	1/3 Bar Suction	1 Bar Suction	15 Bar Suction	Particle-Size Analysis, Wt. % Sand -2.0 +0.05 mm	Silt -0.05 +0.002 mm	Clay -0.002 mm	Textural Class
A11	0	11	0.92	50.5	34.5	27.6	19.8	18.0	58.0	24.0	Silt loam
A12	11	20	0.96	58.4	33.9	25.2	17.5	23.0	66.5	10.5	Silt loam
C1	20	37	0.99	51.3	31.7	24.5	16.8	20.0	66.5	13.5	Silt loam
C2	37	70	1.08	45.9	31.4	25.0	15.6	22.0	58.5	19.5	Silt loam
C3	70	86	1.18	48.2	37.7	26.7	16.7	12.0	66.0	22.0	Silt loam
A1b	86	117	1.18	50.9	36.9	29.9	19.4	10.0	62.0	28.0	Silty clay loam
C1b	117	137	1.25	45.1	33.0	25.0	15.6	12.0	66.0	22.0	Silt loam

(1) Sample to extract ratio: 1 to 2.

(2) Conductivity for a saturation extract based on the 1 to 2 ratio conductivity data and the 1/3 bar water-holding capacity.

Glendive Series

The Glendive Series consists of soils which are deep, well drained, and which have formed in alluvium, weathered mainly from sedimentary bedrock. These soils are found in narrow valley bottoms and have slopes ranging from 2 to 15%.

The surface A horizon typically is a pale brown silt loam ranging from 12 to 30 cm deep. The underlying material is stratified silt loams, sandy loams, and loamy sands that extend to a depth of 150 cm or deeper.

Water permeability is moderate and the effective rooting depth is 150 cm or more. Available water capacity is moderate. Organic matter content in the surface horizon is medium. Surface runoff is slow and the erosion hazard is rated as moderate. These soils are calcareous throughout and reaction ranges from moderately to strongly alkaline. Coarse fragments, less than 1 inch in diameter, make up 5 to 15% of the 25 to 100 cm depth.

Glendive soils are generally dominated by big sagebrush. In areas that have been burned, rabbitbrush and sometimes greasewood diminate. Common herbaceous species include basin wildrye, western wheatgrass, streambank wheatgrass, Indian ricegrass, squirreltail, and Nevada bluegrass. These soils are generally used for livestock grazing and wildlife habitat. These soils form an important part of the mule deer winter range. Some areas of this series are irrigated and used for forage production.

A Glendive pedon considered typical of the series was located on Tract C-a in the SW$\frac{1}{4}$, NE$\frac{1}{2}$, Section 34, T1S, R99W. This pedon was described as

follows:

A1--0-13 cm; pale brown (10 YR 6/3) silt loam; dark brown (10 YR 4/3) when moist; weak fine granular parting to weak coarse platy structure; soft, very friable, nonsticky and nonplastic; common fine roots; calcareous, moderately alkaline; clear smooth boundary.

C1--13 to 53 cm; pale brown (10 YR 6/3) fine channery silt loam; dark brown (10 YR 4/3) when moist; weak medium subangular blocky parting to weak fine granular structure; soft, very friable, nonsticky and nonplastic; common fine roots; calcareous, moderately alkaline; clear wavy boundary.

C2--53 to 80 cm; very pale brown (10 YR 7/3) very fine channery silt loam; pale brown (10 YR 6/3) when moist; massive; soft, very friable, nonsticky and nonplastic; common fine roots; free calcium visible; strongly calcareous, moderately alkaline; clear wavy boundary.

C3--80 to 115 cm; very pale brown (10 YR 7/3) fine channery silt loam; brown (10 YR 5/3) when moist; massive; soft, very friable, nonsticky and nonplastic; common fine roots; strongly calcareous, moderately alkaline; clear wavy boundary.

C4--115 to 139 cm; pale brown (10 YR 6/3) silt loam; dark brown (10 YR 4/3) when moist; massive; soft, very friable, nonsticky and nonplastic; common fine roots; calcareous,

moderately alkaline; clear wavy boundary.

C5--139 to 174 cm; pale brown (10 YR 6/3) fine channery silt loam; dark brown (10 YR 4/3) when moist; massive; soft, very friable, slightly sticky and slightly plastic; few fine roots; calcareous, moderately alkaline.

All horizons were nonsodic and, with the exception of the C5 horizon, nonsaline (Table 9). The accumulation of salts in the 139-174 cm depth is unlikely to have any measurable effect on plant growth. Plant nutrients are present in generally adequate to ample quantities. Some horizons are relatively low in nitrogen and phosphorus, but these seem to be sufficient in nitrogen and phosphorus when the entire profile is considered. The accumulation of nitrate in the lower portion of the profile is unusual. Nitrate that was formed in the upper horizons may have been leached and accumulated in the C5 horizon, but this explanation is not entirely satisfactory. No unusual concentrations of trace elements were detected in the horizons. Lead and fluoride were slightly higher than the concentration found in the study area. Physical properties did not display much variation from horizon to horizon.

TABLE 9

Chemical and Physical Traits of a Glendive Profile

Horizon	Depth, cm From	Depth, cm To	pH in Water	pH in 0.01M $CaCl_2$	Soluble Salt Electrical Conductivity mmhos/cm (1)	Soluble Salt Electrical Conductivity mmhos/cm (2)	Sodium Water Soluble (milliequivalents/100g)	Sodium NH_4 Acetate Soluble (milliequivalents/100g)	Cation Exchange Capacity (milliequivalents/100g)	Exchangeable Sodium Percentage
A1	0	13	8.1	7.9	0.52	2.0	0.39	0.60	36.1	0.58
C1	13	53	8.2	8.0	0.46	1.9	0.39	1.30	32.2	2.83
C2	53	80	8.0	8.0	0.46	2.1	0.37	1.90	26.9	5.69
C3	80	115	8.0	8.0	0.57	2.4	0.36	0.90	31.7	1.70
C4	115	139	8.0	7.9	0.92	3.7	0.38	0.90	32.2	1.61
C5	139	174	8.0	8.0	2.32	8.8	0.98	1.90	31.7	2.90

Horizon	Depth, cm		Ammonium	Nitrate	Phosphorus $NaHCO_3$ Extractable	Potassium Available	Water Soluble					DTPA Extractable			
	From	To	ppm	ppm	ppm	ppm	Magnesium ppm	Calcium ppm	Potassium ppm	Sulfate ppm	Boron ppm	Copper ppm	Manganese ppm	Iron ppm	Zinc ppm
A1	0	13	24.5	0.1	16	500	6.6	37.9	9.0	131	0.8	2.0	38	64	1.8
C1	13	53	14.7	0.1	7	360	6.6	34.3	8.1	86	0.6	2.0	34	52	0.8
C2	53	80	10.0	3.9	6	245	6.0	32.9	6.0	78	0.6	1.8	28	76	2.6
C3	80	115	19.2	12.4	6	370	10.0	46.1	8.2	72	0.5	2.2	27	58	0.8
C4	115	139	12.6	133.0	5	235	24.2	89.9	7.2	102	0.6	2.0	28	65	1.1
C5	139	174	13.3	332.0	10	150	55.2	164.4	12.0	141	<0.5	2.0	32	54	1.2

Horizon	Depth, cm		Molybdenum Anion Exchangeable	Organic Matter	Gypsum Requirement	Lime Requirement	Total							
	From	To	ppm	%	MEQ/100g	lbs $CaCO_3$ per Acre	Phosphorus ppm	Arsenic ppm	Cadmium ppm	Chloride ppm	Chromium ppm	Cobalt ppm	Fluoride ppm	Mercury ppb
A1	0	13	0.2	4.41	<0.2	0	678	10	<0.5	1200	35	6	620	20
C1	13	53	0.4	3.02	<0.2	0	648	5	<0.5	700	40	8	680	15
C2	53	80	0.4	1.88	<0.2	0	729	20	<0.5	700	35	6	720	25
C3	80	115	0.3	2.43	<0.2	0	735	10	<0.5	700	30	8	700	15
C4	115	139	0.3	2.33	<0.2	0	681	10	<0.5	1000	30	4	620	20
C5	139	174	0.3	2.67	<0.2	0	693	10	<0.5	700	40	9	680	15

Horizon	From	To	Total		Selenium Available	NH_4 Acetate Extractable		Uranium
			Antimony ppm	Vanadium ppm	ppb	Nickel ppm	Lead ppm	ppm
A1	0	13	<1	70	10	1.0	2.0	<2.0
C1	13	53	<1	70	20	1.2	1.8	<2.0
C2	53	80	1	60	10	1.0	2.0	<2.0
C3	80	115	<1	60	10	1.0	2.0	<2.0
C4	115	139	<1	20	<10	1.0	2.0	<2.0
C5	139	174	<1	70	60	1.2	2.0	<2.0

Horizon	Depth, cm		Bulk Density	Water-Holding Capacity, % (Dry Sample Wt. Basis)				Particle-Size Analysis, Wt. %			Textural Class
	From	To	g/cm^3	1/10 Bar Suction	1/3 Bar Suction	1 Bar Suction	15 Bar Suction	Sand -2.0+0.05 mm	Silt -0.05+0.002 mm	Clay -0.002 mm	
A1	0	13	0.90	43.7	26.6	20.6	12.6	26.0	60.0	14.0	Silt loam
C1	13	53	1.08	36.4	24.8	21.1	11.4	32.0	52.5	15.5	Silt loam
C2	53	80	1.13	26.5	22.2	18.9	11.7	36.0	50.0	14.0	Silt loam
C3	80	115	1.20	35.0	23.8	19.6	12.8	31.0	54.5	14.5	Silt loam
C4	115	139	1.12	40.6	24.9	19.3	11.9	28.0	57.0	15.0	Silt loam
C5	139	174	1.20	37.7	26.4	21.7	12.2	31.0	60.5	8.5	Silt loam

(1) Sample to extract ratio: 1 to 2.

(2) Conductivity for a saturation extract based on the 1 to 2 ratio conductivity data and the 1/3 bar water-holding capacity.

Castner Series

Soils of the Castner Series are shallow, well drained, and found on upland ridges and ridge tops where the slope ranges from 15-50%. These soils have formed in sandstone residuum.

Typically, the surface layer of a Castner soil is a brown very channery loam approximately 15 cm thick. The subsoil is a brown very flaggy loam about 10 cm thick and overlies hard sandstone. Lime coats the underside of the rock fragments found in the subsoil.

Water permeability is moderate and the effective rooting depth is 50 cm or less. The available water capacity is low. Surface runoff is moderate and the erosion hazard is slight to moderate. Rock fragments occupy approximately 40% of the volume in the surface horizon and approximately 50% of the volume in the subsoil.

Native vegetation on Castner soils is dominated by mountain mahogany, serviceberry, antelope bitterbrush, big sagebrush, bluebunch wheatgrass, western wheatgrass, Junegrass, and Indian ricegrass. These soils are used extensively for mule deer winter range and, to a limited extent, by snowshoe hare and cattle.

A Castner pedon was located in the SE$\frac{1}{4}$, SW$\frac{1}{4}$, Section 31, T1S, R99W. This pedon was described as follows:

A0--5 cm; partially decomposed shrub litter.

A1--0 to 8 cm; dark grayish brown (10 YR 4/2) channery silt loam, very dark grayish brown (10 YR 3/2) when moist;

moderate medium granular structure; soft, very friable, slightly sticky and slightly plastic; abundant medium and fine roots; noncalcareous, mildly alkaline, clear smooth boundary.

B2--8 to 22 cm; brown (10 YR 4/3) flaggy loam, dark brown (10 YR 3/3) moist; weak fine subangular blocky structure parting to moderate granules; hard, friable, slightly sticky and slightly plastic; common fine roots; slightly calcareous, moderately alkaline; gradual smooth boundary.

Cca--22 to 64 cm; brown (10 YR 4/3) very flaggy loam, dark brown (10 YR 3/3) moist; massive; hard, friable, slightly sticky and slightly plastic; common fine roots; strongly calcareous, moderately alkaline; gradual smooth boundary.

R--64 cm; hard, white sandstone.

These horizons did not display any unusual physical or chemical traits (Table 10). The horizons were nonsaline and nonsodic. With the exception of nitrogen, plant nutrients are present in adequate-to-ample amounts. The concentration of nitrogen appears rather low, but rapid cycling of this nutrient may supply plants with adequate amounts of nitrogen. Percentage organic matter is rather high. Shrubs, many of them deciduous, are the dominant form of vegetation on Castner soils. The annual shedding of leaves, which are readily decomposed, maintains a relatively high level of soil organic matter. Trace element concentrations are within the ranges expected and in some cases slightly less than the concentrations found in the study area.

Physical properties of these horizons show an increasing bulk density as depth increases, a relatively constant water-holding capacity, and a decreasing percentage clay and an increasing percentage sand from the A to the C horizons.

TABLE 10

Chemical and Physical Traits of a Castner Profile

Horizon	Depth, cm From	Depth, cm To	pH in Water	pH in 0.01M $CaCl_2$	Soluble Salt Electrical Conductivity mmhos/cm (1)	Soluble Salt Electrical Conductivity mmhos/cm (2)	Sodium Water Soluble (milliequivalents/100 g)	Sodium NH_4 Acetate Soluble (milliequivalents/100 g)	Cation Exchange Capacity (milliequivalents/100 g)	Exchangeable Sodium Percentage
A1	0	8	7.5	7.2	0.35	1.1	0.06	0.47	64.2	0.6
B2	8	22	8.3	7.7	0.28	0.9	0.06	0.38	62.4	0.5
Cca	22	64	8.3	7.8	0.26	0.9	0.07	0.47	64.2	0.6

Horizon	Depth, cm From	Depth, cm To	Ammonium ppm	Nitrate ppm	Phosphorus $NaHCO_3$ Extractable ppm	Potassium Available ppm	Water Soluble Magnesium ppm	Water Soluble Calcium ppm	Water Soluble Potassium ppm	Water Soluble Sulfate ppm	Water Soluble Boron ppm	DTPA Extractable Copper ppm	DTPA Extractable Manganese ppm	DTPA Extractable Iron ppm	DTPA Extractable Zinc ppm
A1	0	8	7.7	1.5	15	510	7.8	57.9	9.7	153	<0.5	2.4	79	140	2.0
B2	8	22	13.0	0.4	12	450	4.4	53.2	5.1	115	<0.5	2.0	31	134	1.2
Cca	22	64	7.7	0.8	9	370	4.4	46.1	3.4	85	<0.5	1.6	28	118	1.6

Horizon	Depth, cm From	Depth, cm To	Molybdenum Anion Exchangeable ppm	Organic Matter %	Gypsum Requirem't MEQ/100 g	Lime Requirem't lb $CaCO_3$ per Acre	Total Phosphorus ppm	Total Arsenic ppm	Total Cadmium ppm	Total Chloride ppm	Total Chromium ppm	Total Cobalt ppm	Total Fluoride ppm	Total Mercury ppb
A1	0	8	0.2	5.78	2.4	0	827	5	<0.5	600	45	10	380	10
B2	8	22	0.1	3.36	<0.2	0	404	5	<0.5	600	45	10	390	10
Cca	22	64	0.1	2.49	<0.2	0	1270	5	<0.5	600	50	8	370	<10

Horizon	Depth, cm From	Depth, cm To	Total Antimony ppm	Total Vanadium ppm	Selenium Available ppb	NH_4 Acetate Extractable Nickel ppm	NH_4 Acetate Extractable Lead ppm	Uranium ppm
A1	0	8	1	70	10	0.8	0.7	2
B2	8	22	<1	70	10	1.0	1.1	<2
Cca	22	64	<1	65	10	1.2	1.1	<2

Horizon	Depth, cm From	Depth, cm To	Bulk Density g/cm^3	Water-Holding Capacity, % (Dry Sample Wt. Basis) 1/10 Bar Suction	Water-Holding Capacity, % (Dry Sample Wt. Basis) 1/3 Bar Suction	Water-Holding Capacity, % (Dry Sample Wt. Basis) 1 Bar Suction	Water-Holding Capacity, % (Dry Sample Wt. Basis) 15 Bar Suction	Particle-Size Analysis, Wt. % Sand -2.0 +0.05 mm	Particle-Size Analysis, Wt. % Silt -0.05 +0.002 mm	Particle-Size Analysis, Wt. % Clay -0.002 mm	Textural Class
A1	0	8	1.10	37.6	31.0	25.2	17.7	24.0	54.0	22.0	Silt loam
B2	8	22	1.19	38.6	30.2	24.1	15.2	30.0	53.0	17.0	Loam
Cca	22	64	1.30	41.6	30.6	23.9	15.7	36.0	52.5	11.5	Loam

(1) Sample to extract ratio: 1 to 2.

(2) Conductivity for a saturation extract based on the 1 to 2 ratio conductivity data and the 1/3 bar water-holding capacity.

Rentsac Series

Soils of the Rentsac series are shallow, skeletal, well drained, and formed in residuum from sandstone that is usually horizontally fractured. These soils typically occur on foothills and ridge tops where slopes range from 5 to 50%.

The A horizon is typically a pale brown very chennery sandy loam or loam approximately 10 cm thick. Coarse fragments range from 25 to 40% of the total, with most of the fragments being less than 8 cm in diameter. The underlying layer is a pale brown very channery sandy loam or loam about 16 cm thick. This layer has 60% coarse fragments with approximately 10% of the fragments larger than 8 cm in diameter. The substrata is a pale brown extremely channery sandy loam about 16 cm thick and overlies fractured hard sandstone.

Rentsac soils have rapid permeability. Effective rooting depth is less than 50 cm. The organic matter content in the surface horizon is medium. Available water-holding capacity is low. Surface runoff is medium and erosion hazard ranges from slight to moderate. These soils are calcareous and moderately alkaline throughout. Lime coatings can be found on the underside of coarse fragments in the subsurface horizons.

The dominant vegetation on the Rentsac series is either pinyon-juniper or big sagebrush. Other woody plants commonly found include mountain mahogany, serviceberry, and bitterbrush. Herbaceous vegetation includes western wheatgrass, elk sedge, needle-and-thread, Nevada bluegrass, Indian

ricegrass, squirreltail, hollyleaf clover, western wallflower, and others. With very few exceptions, soils of the Rentsac series are used for wildlife habitat and livestock grazing.

A typical pedon of the Rentsac series was found in the NE$\frac{1}{4}$, NE$\frac{1}{4}$, Section 10, T2S, R99W. A description of this pedon follows:

A1--0 to 11 cm; grayish brown (10 YR 5/2) channery loam; dark brown (10 YR 3/3) when moist; weak medium subangular block parting to weak fine granular structure; slightly hard, very friable, slightly sticky and slightly plastic; 40 percent sandstone channery; calcareous, moderately alkaline; clear smooth boundary.

AC--11 to 25 cm; very pale brown (10 YR 7/3) very channery loam; brown (10 YR 3/3) when moist; weak fine granular structure; soft, friable, slightly sticky and slightly plastic; 60% sandstone channery; calcareous, moderately alkaline; clear wavy boundary.

Cr--25 to 42 cm; very pale brown (10 YR 8/3) extremely channery loam; light yellowish brown (10 YR 6/4) when moist; massive; soft, friable, slightly sticky and slightly plastic; 70% sandstone channery; calcareous, moderately alkaline; clear wavy boundary.

R--42 cm; highly fractured very pale brown Unita sandstone; 20% of the voids are filled with loam as described above.

The chemical and physical properties of this pedon are given in Table 11. The genetic horizons of this Rentsac profile are nonsaline and

nonsodic. The R horizon is bedrock which is presumably like the parent rock in the C horizon from which the adjacent overlying horizons were formed. This material is saline, sodic, and very strongly alkaline. The concentration of most macronutrients is lower than the concentration found for the study area, but these appears to be adequate amounts of macronutrients for normal plant growth. Micronutrients occur in concentrations considered ample for plant needs. This profile contained relatively high percentages of organic matter. Both the AC and the Cr horizons contained considerable rock and roots were concentrated in the unconsolidated portion of the pedon. Soil samples were taken from this unconsolidated part and, therefore, contained considerable amounts of organic matter. Roots were essentially absent in the R horizon. The concentration of trace elements was within the ranges considered normal for surface soils. Working with a Rentsac profile, Mahmoud (1977) found chemical traits similar to those listed. Physical properties were within the ranges expected and considered typical for this area.

TABLE 11

Chemical and Physical Traits of a Rentsac Profile

Horizon	Depth, cm From	Depth, cm To	pH in Water	pH in 0.01M $CaCl_2$	Soluble Salt Electrical Conductivity mmhos/cm (1)	Soluble Salt Electrical Conductivity mmhos/cm (2)	Sodium Water Soluble (milliequivalents/100 g)	Sodium NH_4 Acetate Soluble (milliequivalents/100 g)	Cation Exchange Capacity (milliequivalents/100 g)	Exchangeable Sodium Percentage
A1	0	11	8.0	7.8	0.53	2.2	0.53	1.40	46.9	1.86
AC	11	25	8.0	7.9	0.52	1.7	0.39	0.60	61.1	0.34
Cr	25	42	8.1	8.0	0.49	1.7	0.40	1.20	39.2	2.04
R	42	64	9.2	8.6	1.82	6.7	2.70	11.50	29.5	29.80

Horizon	Depth, cm From	Depth, cm To	Ammonium ppm	Nitrate ppm	Phosphorus $NaHCO_3$ Extractable ppm	Potassium Available ppm	Water Soluble Magnesium ppm	Water Soluble Calcium ppm	Water Soluble Potassium ppm	Water Soluble Sulfate ppm	Water Soluble Boron ppm	DTPA Extractable Copper ppm	DTPA Extractable Manganese ppm	DTPA Extractable Iron ppm	DTPA Extractable Zinc ppm
A1	0	11	11.3	0.6	15	535	5.7	37.5	8.6	139	0.7	1.0	63	192	2.2
AC	11	25	5.3	1.3	14	150	4.8	47.2	6.2	150	0.6	1.2	48	140	1.4
Cr	25	42	6.0	1.2	9	165	5.1	36.4	5.0	128	0.7	1.0	42	144	1.4
R	42	64	4.0	0.7	3	155	0.7	8.2	11.8	486	0.9	0.6	23	174	1.6

Horizon	Depth, cm From	Depth, cm To	Molybdenum Anion Exchangeable ppm	Organic Matter %	Gypsum Requirement MEQ/100 g	Lime Requirement lbs $CaCO_3$ per Acre	Total Phosphorus ppm	Total Arsenic ppm	Total Cadmium ppm	Total Chloride ppm	Total Chromium ppm	Total Cobalt ppm	Total Fluoride ppm	Total Mercury ppb
A1	0	11	0.4	4.40	<0.2	0	428	5	<0.5	900	40	8	360	15
AC	11	25	0.3	5.71	<0.2	0	317	5	<0.5	900	30	4	360	20
Cr	25	42	0.3	[illegible].48	<0.2	0	488	5	<0.5	1300	30	4	360	20
R	42	64	0.2	0.80	1.4	0	528	5	<0.5	900	35	4	400	15

Horizon	Depth, cm From	Depth, cm To	Total Antimony ppm	Total Vanadium ppm	Selenium Available ppb	NH_4 Acetate Extractable Nickel ppm	NH_4 Acetate Extractable Lead ppm	Uranium ppm
A1	0	11	<1	50	20	1.2	2.0	<2
AC	11	25	<1	70	10	1.6	2.4	<2
Cr	25	42	<1	40	10	1.6	2.2	<2
R	42	64	<1	40	30	1.2	1.8	<2

Horizon	Depth, cm From	Depth, cm To	Bulk Density g/cm3	Water-Holding Capacity, % (Dry Sample Wt. Basis) 1/10 Bar Suction	Water-Holding Capacity, % (Dry Sample Wt. Basis) 1/3 Bar Suction	Water-Holding Capacity, % (Dry Sample Wt. Basis) 1 Bar Suction	Water-Holding Capacity, % (Dry Sample Wt. Basis) 15 Bar Suction	Particle-Size Analysis, Wt. % Sand -2.0+0.05 mm	Particle-Size Analysis, Wt. % Silt -0.05+0.002 mm	Particle-Size Analysis, Wt. % Clay -0.002 mm	Textural Class
A1	0	11	1.13	40.0	24.5	19.9	12.1	42.0	48.0	10.0	Loam
AC	11	25	1.14	45.5	31.1	25.9	18.1	40.0	45.0	15.0	Loam
Cr	25	42	1.41	44.6	28.3	23.2	15.4	44.0	46.0	10.0	Loam
R	42	64	-	76.8	20.3	17.1	10.6	59.0	34.0	7.0	Sandy loam

(1) Sample to extract ratio: 1 to 2.

(2) Conductivity for a saturation extract based on the 1 to 2 ratio conductivity data and the 1/3 bar water-holding capacity.

Piceance Series

Soils of the Piceance series are moderately deep, well drained, and have formed in residuum from sandstone and modified with aeolian material. These soils are found on upland slopes and on the lee side of ridges. Slope ranges from 5 to 15%.

Typically, the surface horizon of Piceance soils is a brown loam or sandy loam ranging from 10 to 25 cm thick. The subsoil or B horizon is a brown or light brown silt loam approximately 40 cm thick. The substratum is a pale brown chennery loam about 30 cm thick and overlies hard sandstone. There is a layer of lime accumulation in the lower part of the B horizon and in the substratum.

Permeability is rapid and the effective rooting depth is 50 to 100 cm. The available water capacity is moderate. Organic matter content in the surface layer is medium. Surface runoff is slow to medium and the erosion hazard is slight to moderate.

Big sagebrush is the dominant form of vegetation on soils of the Piceance series. Other vegetation commonly found includes rabbitbrush, needle-and-thread, Indian ricegrass, muttongrass, sandbery bluegrass, wheatgrasses, lupine, hollyleaf clover, phlox, fleabane, buckwheat, and others. Livestock grazing and wildlife habitat are the dominant uses of these soils.

A typical pedon of the Piceance series was located in the NE$\frac{1}{4}$, NW$\frac{1}{4}$, Section 10, T2S, R99W, and is described below.

A1--0 to 10 cm; brown (10 YR 5/3) loam, dark brown (10 YR 3/3) when moist; medium fine granular structure; slightly hard, very friable, slightly plastic and slightly sticky; common fine and very fine roots; noncalcareous, mildly alkaline; clear smooth boundary.

B1--10 to 36 cm; brown (10 YR 5/3) silt loam; dark brown (10 YR 4/3) when moist; weak moderate subangular blocky structure; slightly hard, very friable, slightly sticky and slightly plastic; common fine and very fine roots; noncalcareous, moderately alkaline; clear wavy boundary.

B2--36 to 53 cm; brown (10 YR 5/3) silt loam, dark brown (10 YR 4/3) when moist; moderate medium subangular blocky structure; slightly hard, friable, slightly sticky and slightly plastic; common fine and very fine roots; calcareous, moderately alkaline; clear wavy boundary.

C1--53 to 81; pale brown (10 YR 6/3) loam, dark brown (10 YR 4/3) when moist; massive; slightly hard, friable, slightly sticky and slightly plastic; common very fine roots; free lime visible; highly calcareous, strongly alkaline; clear wavy boundary.

R--81 cm; hard sandstone.

These four horizons were nonsaline and nonsodic (Table 12). The concentrations of nitrogen and extractable phosphorus were relatively low in the subsurface horizons, but not at a level where plant growth would be

noticeably affected. The concentration of water-soluble macronutrients was generally lower than that found for the study area while the concentration of micronutrients was slightly higher. These shifts in the nutrient concentration are unlikely to affect plant growth. Percentage organic matter, the concentration of trace elements, and physical traits were within the ranges expected and close to the average values found for the study area.

TABLE 12

Chemical and Physical Traits of a Piceance Profile

Horizon	Depth, cm		pH	pH in	Soluble Salt Electrical Conductivity mmhos/cm	Soluble Salt Electrical Conductivity mmhos/cm	Sodium Water Soluble	Sodium NH_4 Acetate Soluble	Cation Exchange Capacity	Exchangeable Sodium
	From	To	in Water	0.01M $CaCl_2$	(1)	(2)	(milliequivalents/100 g)			Percentage
A1	0	10	7.7	7.0	0.54	2.3	0.10	2.10	39.0	5.13
B1	10	36	7.9	7.2	0.33	1.4	0.30	0.90	40.1	1.50
B2	36	53	8.1	7.4	0.36	1.6	0.36	1.60	34.4	3.60
C1	53	81	8.6	7.6	0.47	1.8	0.77	4.70	35.5	11.07

					Phosphorus		Water Soluble					DTPA Extractable			
	Depth, cm		Ammonium	Nitrate	$NaHCO_3$ Extractable	Potassium Available	Magnesium	Calcium	Potassium	Sulfate	Boron	Copper	Manganese	Iron	Zinc
Horizon	From	To	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
A1	0	10	13.9	1.4	9	600	4.2	18.6	18.0	75	0.8	1.8	70	148	1.8
B1	10	36	8.6	<0.1	5	355	5.4	24.3	5.4	50	0.8	1.6	44	102	0.8
B2	36	53	12.0	<0.1	5	345	5.1	21.4	10.3	45	<0.5	1.4	36	92	1.6
C1	53	81	10.0	<0.1	4	345	3.0	10.0	8.7	65	<0.5	1.6	42	98	1.6

			Molybdenum			Lime	Total							
	Depth, cm		Anion Exchangeable	Organic Matter	Gypsum Requirement	Requirement lb $CaCO_3$	Phosphorus	Arsenic	Cadmium	Chloride	Chromium	Cobalt	Fluoride	Mercury
Horizon	From	To	ppm	%	MEQ/100 g	per Acre	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppb
A1	0	10	0.3	2.28	<0.2	0	536	5	<0.5	1100	40	9	420	25
B1	10	36	0.3	1.52	<0.2	0	547	5	<0.5	900	40	10	440	20
B2	36	53	0.2	1.21	<0.2	0	548	5	<0.5	1100	40	10	400	15
C1	53	81	0.2	1.14	0.6	0	490	<5	<0.5	900	40	8	440	15

			Total		Selenium	NH_3 Acetate Extractable		
	Depth, cm		Antimony	Vanadium	Available	Nickel	Lead	Uranium
Horizon	From	To	ppm	ppm	ppb	ppm	ppm	ppm
A1	0	10	<1	60	10	0.8	1.4	<2.0
B1	10	36	<1	60	<10	1.0	1.8	<2.0
B2	36	53	<1	50	<10	1.2	1.8	<2.0
C1	53	81	<1	60	<10	1.0	1.6	<2.0

			Bulk	Water-Holding Capacity, % (Dry Sample Wt. Basis)				Particle-Size Analysis, Wt. %			
	Depth, cm		Density	1/10 Bar	1/3 Bar	1 Bar	15 Bar	Sand	Silt	Clay	
Horizon	From	To	g/cm^3	Suction	Suction	Suction	Suction	-2.0 +0.05 mm	-0.05 +0.002 mm	-0.002 mm	Textural Class
A1	0	10	1.20	35.5	23.4	18.1	12.2	33.5	46.5	20.0	Loam
B1	10	36	1.24	36.0	22.8	17.7	11.1	40.0	52.0	8.0	Silt loam
B2	36	53	1.30	38.9	23.0	18.6	12.0	36.0	52.0	12.0	Silt loam
C1	53	81	1.23	40.0	26.5	20.5	12.4	32.0	48.5	19.5	Loam

(1) Sample to extract ratio: 1 to 2.

(2) Conductivity for a saturation extract based on 1 to 2 ratio conductivity data and the 1/3 bar water-holding capacity.

Redcreek Series

The Redcreek series consists of shallow, well drained soils that have formed in sandy material weathered from underlying calcareous, massive sandstone. These soils are found on foothills and ridge tops where slopes range from 5 to approximately 30%.

The A horizon is a pale brown to brown sandy loam about 14 cm thick. The underlying horizon is a pale to light brown channery sandy loam. Substrata is a channery to very channery sandy loam ranging from 35 to 80 cm thick. Coarse fragments account for as much as 80% of the material found in the lower portions of the substrata. Permeability is moderately rapid, the available water capacity is low, and the effective rooting depth ranges from 25 to 50 cm. Surface runoff is slow, and the erosion hazard is slight. Reaction is mildly alkaline to moderately alkaline throughout; all horizons are calcareous. Lime coatings on the surface of rocks can be found in the lower portions of the substrata.

The vegetation on these soils is typically dominated by pinyon pine and Utah juniper. Understory species commonly include big sagebrush, serviceberry, mountain mahogany, bluebunch wheatgrass, elk sedge, squirreltail, Indian ricegrass, Junegrass, wolly loco, and buckwheat. Use of these soils includes livestock grazing and wildlife habitat.

A pedon considered typical of the Redcreek series was found on Tract C-a and was located in the NW$\frac{1}{4}$, NE$\frac{1}{4}$, Section 4, T2S, R99W. This pedon was described as follows:

A0--3 cm; partially decomposed tree litter.

A1--0 to 13 cm; brown (7.5 YR 5/4) sandy loam; dark brown (7.5 YR 4/2) when moist; weak fine subangular blocky parting to moderate fine granular structure; soft, very friable, nonsticky and nonplastic; noncalcareous, moderately alkaline; clear smooth boundary.

AC--13 to 23 cm; light brown (7.5 YR 6/4) sandy loam; dark brown (7.5 YR 4/4) when moist; weak medium subangular blacky parting to weak fine granular structure; 5% fine channers; soft, very friable, nonsticky and nonplastic; calcareous, moderately alkaline; clear wavy boundary.

C1--23 to 42 cm; light yellowish brown (10 YR 6/4) sandy loam; dark yellowish brown (10 YR 4/4) when moist; massive; slightly hard, very friable, nonsticky and nonplastic; 10% channers; common fine roots; some lime accumulation on coarse fragments; calcareous, moderately alkaline; clear wavy boundary.

Crca--42 to 102 cm; white (10 YR 8/2) light sandy loam; very pale brown (10 YR 7/3) when moist; massive; slightly hard, very firm slightly sticky and nonplastic; fractured sandstone with lime enrichment; 20% of the voids are filled with calcareous sandy loam material; highly calcareous, moderately alkaline; clear wavy boundary.

R--102 cm; sandstone bedrock.

The chemical and physical properties of this pedon are given in Table 13. These genetic horizons were both nonsaline and nonsodic. The concentration of plant nutrients was within the range expected, with the exception of extractable phosphorus in the surface epipedon. For unknown reasons, the phosphorus in this horizon was relatively high. The slight increase in percentage organic matter in the Crca horizon was caused by roots being concentrated in the unconsolidated portion of the horizon. Physical traits and the concentration of trace elements suggested nothing unusual in these horizons.

TABLE 13

Chemical and Physical Traits of a Redcreek Profile

Horizon	Depth, cm From	Depth, cm To	pH in Water	pH in 0.01M $CaCl_2$	Soluble Salt Electrical Conductivity mmhos/cm (1)	Soluble Salt Electrical Conductivity mmhos/cm (2)	Sodium Water Soluble (milliequivalents/100 g)	Sodium NH_4 Acetate Soluble (milliequivalents/100 g)	Cation Exchange Capacity (milliequivalents/100 g)	Exchangeable Sodium Percentage
A1	0	13	7.9	7.5	0.25	1.5	0.20	1.90	39.6	4.3
AC	13	23	8.0	7.5	0.53	3.3	0.62	1.10	36.5	1.3
C1	23	42	8.1	7.8	0.54	3.1	0.43	2.90	40.0	6.2
Crca	42	102	8.0	8.0	0.63	2.7	0.54	1.40	37.4	2.3

Horizon	Depth, cm From	Depth, cm To	Ammonium ppm	Nitrate ppm	Phosphorus $NaHCO_3$ Extractable ppm	Potassium Available ppm	Water Soluble Magnesium ppm	Water Soluble Calcium ppm	Water Soluble Potassium ppm	Water Soluble Sulfate ppm	Water Soluble Boron ppm	DTPA Extractable Copper ppm	DTPA Extractable Manganese ppm	DTPA Extractable Iron ppm	DTPA Extractable Zinc ppm
A1	0	13	7.3	0.7	44	375	6.6	17.9	11.0	751	0.8	0.8	68	128	1.6
AC	13	23	9.3	0.4	16	330	5.7	19.7	6.3	161	0.6	0.6	51	106	1.0
C1	23	42	8.6	0.1	11	390	9.3	27.9	6.0	126	0.6	0.8	53	176	1.4
Crca	42	102	9.3	1.1	9	165	9.3	53.6	5.8	177	<0.5	1.4	46	114	1.0

Horizon	Depth, cm From	Depth, cm To	Molybdenum Anion Exchangeable ppm	Organic Matter %	Gypsum Requirement MEQ/100 g	Lime Requirement lbs $CaCO_3$ per Acre	Total Phosphorus ppm	Total Arsenic ppm	Total Cadmium ppm	Total Chloride ppm	Total Chromium ppm	Total Cobalt ppm	Total Fluoride ppm	Total Mercury ppb
A1	0	13	0.4	3.59	<0.2	0	595	10	<0.5	1500	50	14	520	35
AC	13	23	0.4	1.49	<0.2	0	471	10	<0.5	600	55	5	380	15
C1	23	42	0.4	1.15	<0.2	0	281	10	<0.5	700	55	8	440	<10
Crca	42	102	0.3	2.63	<0.2	0	561	10	<0.5	800	65	6	440	15

Horizon	Depth, cm From	Depth, cm To	Total Antimony ppm	Total Vanadium ppm	Selenium Available ppb	NH_4 Acetate Extractable Nickel ppm	NH_4 Acetate Extractable Lead ppm	Uranium ppm
A1	0	13	<1	60	10	0.8	1.4	<2.0
AC	13	23	<1	60	20	0.8	1.4	<2.0
C1	23	42	<1	60	10	1.0	1.4	<2.0
Crca	42	102	<1	50	10	1.4	2.2	<2.0

Horizon	Depth, cm From	Depth, cm To	Bulk Density g/cm^3	Water-Holding Capacity, % (Dry Sample Wt. Basis) 1/10 Bar Suction	Water-Holding Capacity, % (Dry Sample Wt. Basis) 1/3 Bar Suction	Water-Holding Capacity, % (Dry Sample Wt. Basis) 1 Bar Suction	Water-Holding Capacity, % (Dry Sample Wt. Basis) 15 Bar Suction	Particle-Size Analysis, Wt. % Sand -2.0+0.05 mm	Particle-Size Analysis, Wt. % Silt -0.05+0.002 mm	Particle-Size Analysis, Wt. % Clay -0.002 mm	Textural Class
A1	0	13	1.25	23.3	16.7	14.1	10.1	63.0	30.0	7.0	Sandy loam
AC	13	23	1.19	23.7	16.0	13.8	9.5	67.0	27.0	6.0	Sandy loam
C1	23	42	1.40	26.8	17.5	14.8	9.2	65.0	31.0	4.0	Sandy loam
Crca	42	102	1.16	36.4	23.7	20.4	15.0	54.0	38.0	8.0	Sandy loam

(1) Sample to extract ratio: 1 to 2.

(2) Conductivity for a saturation extract based on the 1 to 2 ratio conductivity data and the 1/3 bar water-holding capacity.

Yamac Series

The Yamac series consists of deep, well drained soils that have formed in alluvium and aeolian materials. These soils are generally found on rolling uplands which have slopes ranging from 2 to 15%.

A typical Yamac profile will have a surface layer of brown silt loam about 10 cm thick. The upper portion of the subsoil is a brown silt loam or clay loam approximately 20 cm thick. The lower portion of the subsoil is a highly calcareous pale brown silt loam approximately 70 cm thick.

Water permeability is moderate. The effective rooting depth is 150 cm or more. These soils have a high available water capacity. Organic matter content in the surface layer is medium. Surface runoff is medium and the erosion hazard is slight. Yamac soils are calcareous throughout, and reaction ranges from, moderately alkaline in the surface layer to strongly alkaline in the lower portion of the subsoil.

Generally, Yamac soils are dominated by big sagebrush. Other common shrubs include rabbitbrush, and winterfat. Herbaceous vegetation may include western wheatgrass, streambank wheatgrass, Junegrass, sedge, needle-and-thread, and loco. Yamac soils are generally used for livestock grazing and wildlife habitat, especially mule deer, snowshoe hare, and blue grouse. These soils have a fair potential for dryland farming and as a source of topsoil.

A typical Yamac pedon was found in the NW¼, SW¼, Section 2, T2S, R99W. This pedon was described as follows:

A1--0 to 10 cm; brown (10 YR 5/3) silt loam, dark brown (10 YR 3/3) when moist; weak medium platy parting to medium very fine subangular blocky structure; slightly hard, friable, slightly sticky and slightly plastic; common fine and very fine roots; slightly calcareous, moderately alkaline; clear smooth boundary.

B2--10 to 32 cm; brown (10 YR 5/3) silt loam, dark brown (10 YR 3/3) when moist; medium coarse prismatic parting to moderate fine to medium subangular blocky structure; slightly hard, friable, slightly sticky and slightly plastic; common fine and very fine roots; slightly calcareous, mildly alkaline; clear wavy boundary.

B3ca--32 to 62 cm; pale brown (10 YR 6/3) silt loam, dark brown (10 YR 4/3) when moist; weak medium subangular blocky structure; slightly hard, friable, slightly sticky and slightly plastic; common fine and very fine roots; calcareous, moderately alkaline; clear wavy boundary.

Clca--62 to 110 cm; very pale brown (10 YR 7/3) silt loam, brown (10 YR 4/3) when moist; massive; slightly hard, friable, slightly sticky and slightly plastic; few fine roots; highly calcareous, strongly alkaline; gradual wavy boundary.

C2--110 cm; very pale brown (10 YR 7/3) silt loam, brown (10 YR 4/3) when moist; massive; soft, friable, slightly

sticky and slightly plastic; few fine roots; highly calcareous, moderately alkaline;

The physical and chemical characteristics of this pedon are given in Table 14. All of the horizons were nonsaline and nonsodic. The concentration of plant nutrients appeared normal and adequate to satisfy plant requirements. However, the concentration of almost all the plant nutrients was lower than that found for the study area. Differences in the geologic origin of parent materials may be partially responsible for the different nutrient status. Trace element concentrations were within the range expected and showed no unusual deviations from the average values for Tract C-a and the adjacent areas. Physical traits were rather uniform from horizon to horizon. This data is in general agreement with data collected by Mahmoud (1977). However, Mahmoud found saline and sodic horizons near the base of the pedon.

TABLE 14

Chemical and Physical Traits of a Yamac Profile

Horizon	Depth, cm		pH	pH in	Soluble Salt Electrical Conductivity mmhos/cm	Soluble Salt Electrical Conductivity mmhos/cm	Sodium Water Soluble	Sodium NH_4 Acetate Soluble	Cation Exchange Capacity	Exchangeable Sodium
	From	To	in Water	0.01M $CaCl_2$	(1)	(2)	(milliequivalents/100 g)			Percentage
A1	0	10	8.1	7.5	0.22	0.9	0.14	1.40	38.7	3.3
B2	10	32	7.4	7.4	0.22	0.9	0.15	1.20	30.0	3.5
B3ca	32	62	8.1	7.8	0.23	0.9	0.19	1.30	38.9	2.9
C1ca	62	110	8.6	8.0	0.35	1.3	0.62	2.80	31.3	7.0
C2	110	150	8.3	8.0	0.57	2.4	1.03	4.80	30.0	12.6

Horizon	Depth, cm		Ammonium	Nitrate	Phosphorus $NaHCO_3$ Extractable	Potassium Available	Water Soluble					DTPA Extractable			
	From	To	ppm	ppm	ppm	ppm	Magnesium ppm	Calcium ppm	Potassium ppm	Sulfate ppm	Boron ppm	Copper ppm	Manganese ppm	Iron ppm	Zinc ppm
A1	0	10	18.6	1.2	12	330	5.4	23.9	2.6	58	0.6	1.6	53	46	1.0
B2	10	32	7.3	1.7	4	165	4.0	28.6	1.5	40	0.5	1.4	36	20	0.6
B3ca	32	62	12.0	0.3	3	165	4.6	27.5	1.1	53	0.7	1.0	32	18	0.6
C1ca	62	110	9.3	0.3	3	165	2.5	10.1	2.3	93	0.6	1.0	25	30	0.6
C2	110	150	8.0	0.8	3	175	3.1	7.8	3.0	120	0.8	1.0	27	26	1.0

Horizon	Depth, cm		Molybdenum Anion Exchangeable	Organic Matter	Gypsum Requirement	Lime Requirement lb $CaCO_3$	Total							
	From	To	ppm	%	MEQ/100 g	per Acre	Phosphorus ppm	Arsenic ppm	Cadmium ppm	Chloride ppm	Chromium ppm	Cobalt ppm	Fluoride ppm	Mercury ppb
A1	0	10	0.3	3.19	<0.2	0	588	10	<0.5	1000	45	8	400	20
B2	10	32	0.2	2.20	<0.2	0	606	5	<0.5	1200	45	9	400	20
B3ca	32	62	0.2	1.82	<0.2	0	621	5	<0.5	1100	45	8	440	20
C1ca	62	110	0.2	0.86	<0.2	0	602	10	<0.5	1000	40	6	440	15
C2	110	150	0.2	0.57	<0.2	0	557	<5	<0.5	1200	40	8	440	15

Horizon	Depth, cm		Total		Selenium Available	NH_4 Acetate Extractable		Uranium
	From	To	Antimony ppm	Vanadium ppm	ppb	Nickel ppm	Lead ppm	ppm
A1	0	10	<1	60	<10	0.8	1.2	<2.0
B2	10	32	<1	60	<10	0.8	1.8	<2.0
B3ca	32	62	<1	60	10	1.2	1.8	<2.0
C1ca	62	110	<1	60	<10	1.0	1.6	<2.0
C2	110	150	<1	60	<10	1.0	1.6	<2.0

Horizon	Depth, cm		Bulk Density	Water-Holding Capacity, % (Dry Sample Wt. Basis)				Particle-Size Analysis, Wt. %			Textural Class
	From	To	g/cm^3	1/10 Bar Suction	1/3 Bar Suction	1 Bar Suction	15 Bar Suction	Sand -2.0 +0.05 mm	Silt -0.05 +0.002 mm	Clay -0.002 mm	
A1	0	10	1.23	38.6	25.6	19.0	12.9	30.0	52.5	17.5	Silt loam
B2	10	32	1.23	40.5	24.4	19.3	11.8	27.0	59.0	14.0	Silt loam
B3ca	32	62	1.34	40.3	26.5	20.5	13.7	22.5	61.5	16.0	Silt loam
C1ca	62	110	1.15	38.0	26.2	19.9	12.2	30.0	52.0	18.0	Silt loam
C2	110	150	1.25	34.5	24.2	18.6	10.9	34.0	50.0	16.0	Silt loam

(1) Sample to extract ratio: 1 to 2.

(2) Conductivity for a saturation extract based on the 1 to 2 ratio conductivity data and the 1/3 bar water-holding capacity.

Rivra Series

The Rivra series consists of deep, excessively drained soils that have formed in mixed alluvium of calcareous sandstone and shale origin. These soils are found on alluvial fans and in narrow valleys with slope gradients ranging from 2 to 8%.

Soils of this series are 150 cm deep or deeper with coarse fragments making up 35% or more of the 25 to 100 cm depth. The soil is calcareous throughout, except for the A horizon in some pedons. The A horizon is light brownish gray to pale brown, and texture ranges from fine sandy loam to sand. Permeability is rapid. The effective rooting depth is 150 cm or more. Available water-holding capacity and the organic matter content are low. Both surface runoff and the erosion hazard are medium. In some pedons, buried A horizons can be found.

The vegetation found on Rivra soils is dominated by big sagebrush. Other shrubs commonly found include green rabbitbrush, greasewood, and fringed sage. Herbaceous vegetation commonly consists of western wheatgrass, downy brome, basin wildrye, and Indian ricegrass. Rivra soils are used almost entirely for livestock grazing and for wildlife habitat.

A typical pedon of the Rivra series was found in the NE section of Tract C-a and located 100 ft north of the information center in the NE$\frac{1}{4}$, NE$\frac{1}{4}$, Section 34, T1S, R99W. This soil was described as follows:

A1--0 to 12 cm; pale brown (10 YR 6/3) channery sandy loam; brown (10 YR 4/3) when moist; weak fine granular structure; soft, very friable, nonsticky and nonplastic; common fine roots; calcareous; moderately alkaline; clear smooth boundary.

C1--12 to 33 cm; pale brown (10 YR 6/3) very channery fine sandy loam; dark yellowish brown (10 YR 4/4) when moist; massive; soft, very friable, nonsticky and nonplastic; common fine roots; calcareous, moderately alkaline; clear wavy boundary.

C2--33 to 46 cm; pale brown (10 YR 6/3) channery sandy loam; dark yellowish brown (10 YR 4/4) when moist; massive; soft, very friable, nonsticky and nonplastic; common fine roots; calcareous, moderately alkaline; clear wavy boundary.

C3--46 to 82 cm; pale brown (10 YR 6/3) fine channery sandy loam; dark yellowish brown (10 YR 4/4) when moist; massive; soft, very friable, nonsticky and nonplastic; common fine roots; calcareous, moderately alkaline; clear smooth boundary.

C4--82 to 114 cm; pale brown (10 YR 6/3) fine, sandy loam; dark brown (10 YR 4/3) when moist; massive; soft, very friable, nonsticky and nonplastic; common fine roots; calcareous, moderately alkaline; clear wavy boundary.

C5--114 to 168 cm; pale brown (10 YR 6/3) very channery sandy loam; dark yellowish brown (10 YR 4/4) when moist; massive; soft, very friable, nonsticky and nonplastic; few fine roots;

calcareous, moderately alkaline.

Table 15 shows that this Rivra profile is nonsaline and nonsodic. The concentration of macronutrients in these horizons is substantially lower than the concentrations found in Tract C-a and the adjacent areas. Rivra soils are very sandy and apparently able to retain only relatively small amounts of macronutrients. The concentration of micronutrients is similar to that for the study area. Percentage organic matter is highly variable from horizon to horizon. This lack of spatial pattern is typical of young alluvial soils. Trace element concentrations were within the ranges expected. The rather uniform physical properties of this pedon indicate that little soil weathering has taken place. This pedon has a low potential to retain water for plant absorption.

TABLE 15

Chemical and Physical Traits of a Rivra Profile

Horizon	Depth, cm		pH in Water	pH in 0.01M $CaCl_2$	Soluble Salt Electrical Conductivity mmhos/cm (1)	Soluble Salt Electrical Conductivity mmhos/cm (2)	Sodium Water Soluble	Sodium NH_4 Acetate Soluble	Cation Exchange Capacity	Exchangeable Sodium Percentage
	From	To					(milliequivalents/100g)			
A1	0	12	8.3	8.2	0.30	2.0	0.22	1.70	24.1	6.14
C1	12	33	8.3	8.1	0.28	1.9	0.22	1.50	23.5	5.45
C2	33	46	8.4	8.0	0.34	2.8	0.37	1.70	26.1	5.10
C3	46	82	8.4	7.8	0.38	2.3	0.30	2.10	26.9	6.69
C4	82	114	8.4	8.0	0.40	2.7	0.36	2.00	28.7	5.71
C5	114	168	8.4	8.0	0.48	3.0	0.68	2.70	25.6	7.89

Horizon	Depth, cm		Ammonium ppm	Nitrate ppm	Phosphorus $NaHCO_3$ Extractable ppm	Potassium Available ppm	Water Soluble					DTPA Extractable			
	From	To					Magnesium ppm	Calcium ppm	Potassium ppm	Sulfate ppm	Boron ppm	Copper ppm	Manganese ppm	Iron ppm	Zinc ppm
A1	0	12	4.2	3.5	8	220	3.9	29.3	7.2	97	0.8	0.8	42	102	0.8
C1	12	33	3.5	2.2	3	225	3.0	23.6	6.8	86	0.6	0.6	22	88	1.6
C2	33	46	7.0	2.4	5	160	4.2	25.7	8.6	151	0.5	0.6	25	142	1.2
C3	46	82	3.5	2.9	8	365	4.5	29.3	10.7	193	0.6	1.4	42	176	2.6
C4	82	114	10.5	2.6	8	360	5.1	30.0	10.8	194	0.6	1.0	37	168	1.2
C5	114	168	4.2	11.2	9	285	4.1	26.2	7.8	241	0.9	1.0	28	132	1.3

Horizon	Depth, cm		Molybdenum Anion Exchangeable ppm	Organic Matter %	Gypsum Requirement MEQ/100g	Lime Requirement lbs $CaCO_3$ per Acre	Total							
	From	To					Phosphorus ppm	Arsenic ppm	Cadmium ppm	Chloride ppm	Chromium ppm	Cobalt ppm	Fluoride ppm	Mercury ppb
A1	0	12	0.1	1.11	<0.2	0	582	5	<0.5	1000	50	4	420	20
C1	12	33	0.1	0.46	<0.2	0	539	5	<0.5	1000	50	8	420	15
C2	33	46	0.2	0.54	<0.2	0	514	10	<0.5	1000	50	6	360	20
C3	46	82	0.5	1.11	<0.2	0	539	5	<0.5	1100	50	6	420	20
C4	82	114	0.5	1.09	<0.2	0	607	5	<0.5	1100	50	9	400	20
C5	114	168	0.3	1.03	<0.2	0	609	10	<0.5	900	50	5	400	15

Horizon	Depth, cm		Total		Selenium Available ppb	NH_4 Acetate Extractable		Uranium ppm
	From	To	Antimony ppm	Vanadium ppm		Nickel ppm	Lead ppm	
A1	0	12	<1	20	<10	1.2	1.8	<2
C1	12	33	<1	60	<10	1.0	1.4	<2
C2	33	46	<1	60	<10	0.8	1.6	<2
C3	46	82	<1	60	<10	1.0	1.8	<2
C4	82	114	<1	60	10	1.0	1.6	<2
C5	114	168	<1	60	20	1.0	1.6	<2

Horizon	Depth, cm		Bulk Density g/cm^3	Water-Holding Capacity, % (Dry Sample Wt. Basis)				Particle-Size Analysis, Wt. %			Textural Class
	From	To		1/10 Bar Suction	1/3 Bar Suction	1 Bar Suction	15 Bar Suction	Sand -2.0+0.05 mm	Silt -0.05+0.002 mm	Clay -0.002 mm	
A1	0	12	1.16	18.0	14.7	11.8	8.8	66.0	26.5	7.5	Sandy loam
C1	12	33	1.04	18.3	14.9	12.8	8.9	65.0	27.5	7.5	Sandy loam
C2	33	46	1.10	16.2	12.2	11.0	7.8	68.0	28.5	7.5	Sandy loam
C3	46	82	1.18	26.5	16.3	13.9	9.0	52.5	35.5	12.0	Sandy loam
C4	82	114	1.20	22.0	14.9	12.9	8.8	59.0	29.0	12.0	Sandy loam
C5	114	168	1.13	23.5	16.0	13.4	9.1	60.0	27.0	13.0	Sandy loam

(1) Sample to extract ratio: 1 to 2.

(2) Conductivity for a saturation extract based on the 1 to 2 ratio conductivity data and the 1/3 bar water-holding capacity.

Torriorthent

This unnamed Torriorthent series consists of soils which have formed in colluvial and alluvial material originating from calcareous sandstone or shale. These shallow, well drained soils are generally found on very steep, south-facing slopes and canyon bluffs.

The A horizon ranges from very pale brown to brown sandy loam to silt loam, and contains varying amounts of rock fragments. Subsurface horizons are generally light colored very channery silt loam or loamy sand. Considerable variation is found in almost all soil traits of the Torriorthents. The nature of the parent material, steepness of the slope, aspect, and vegetation vary considerably within this soil type and are major factors in the variable nature of this soil type.

The vegetation occurring on this soil type is sparse. Common components of the vegetation include pinyon pine, Utah juniper, greasewood, shadscale, rabbitbrush, woody buckwheat, Indian ricegrass, primrose, fringe sage, bluebunch wheatgrass, and silver thistle. These soils have severe limitations for essentially all uses, but do serve as a limited wildlife habitat.

Following is a description of a Torriorthent pedon occurring the SE$\frac{1}{4}$, SW$\frac{1}{4}$, Section 34, TIS, R99W.

A1--0 to 11 cm; very pale brown (10 YR 7/3) light silt loam; yellowish brown (10 YR 5/4) when moist; massive; soft, very friable, slight sticky and slightly plastic; highly calcareous, very strongly alkaline; clear smooth boundary.

AC--11 to 37 cm; light gray (10 YR 7/2) very fine channery silt loam; brown (10 YR 5/3) when moist; massive; soft, vary friable, nonsticky and nonplastic; highly calcareous, strongly alkaline; clear wavy boundary; 15% is variegated (5 YR 5/8).

Cr--37 to 49 cm; very pale brown (10 YR 7/3) very channery silt loam; dark brown (10 YR 4/3) when moist; massive; soft, very friable, nonsticky and nonplastic; highly weathered Green River shale; highly calcareous, moderately alkaline; 15% is variegated (5 YR 5/8); clear wavy boundary.

R--49 cm; Green River shale.

The chemical and physical traits of this soil are presented in Table 16. The most striking chemical traits of this Torriorthent are the highly saline and highly sodic nature of this soil. These traits severely restrict plant growth and are undoubtably important factors in the sparse vegetative cover on Torriorthent soils. It appears that these traits are primarily a function of the parent material. The water-soluble macronutrients, especially sulfate, are considerably more concentrated in this torriorthent soil than in the soils of the study area. The concentration of nitrate is also unusually high. Micronutrient concentration is within the range expected, although extractable copper is somewhat more abundant in this profile than in the other soils examined. Organic matter is low, as expected, due to the sparse vegetative cover. Trace element concentrations were within the ranges found for the study area, but in almost all cases this profile had

a higher concentration of trace elements than the average for the study area. This profile has been only slightly weathered and most of the chemical and physical traits appear to reflect the nature of the parent material.

TABLE 16

Chemical and Physical Traits of a Torriorthent Profile

Horizon	Depth, cm		pH	pH	Soluble Salt Electrical Conductivity mmhos/cm	Soluble Salt Electrical Conductivity mmhos/cm	Sodium Water Soluble	Sodium NH_4 Acetate Soluble	Cation Exchange Capacity	Exchangeable Sodium Percentage
	From	To	in Water	in 0.01M $CaCl_2$	(1)	(2)	(milliequivalents/100 g)	(milliequivalents/100 g)	(milliequivalents/100 g)	
A1	0	11	9.7	9.4	8.85	28.9	12.76	32.15	23.5	82.5
AC	11	37	8.6	8.1	14.36	68.1	20.70	25.70	23.3	19.5
Cr	37	49	8.4	7.8	13.19	58.4	18.90	22.30	23.9	14.2

Horizon	Depth, cm		Ammonium	Nitrate	Phosphorus $NaHCO_3$ Extractable	Potassium Available	Water Soluble					DTPA Extractable			
	From	To	ppm	ppm	ppm	ppm	Magnesium ppm	Calcium ppm	Potassium ppm	Sulfate ppm	Boron ppm	Copper ppm	Manganese ppm	Iron ppm	Zinc ppm
A1	0	11	3.3	12.0	16	225	23.5	71.5	44.3	3643	0.8	6.0	29	120	1.6
AC	11	37	7.3	50.0	5	160	67.0	450.3	20.0	3614	0.6	4.4	9	102	1.0
Cr	37	49	10.0	1.8	6	160	136.3	425.2	18.4	6217	0.8	4.0	12	126	1.8

Horizon	Depth, cm		Molybdenum Anion Exchangeable	Organic Matter	Gypsum Requirement	Lime Requirement	Total							
	From	To	ppm	%	MEQ/100 g	lbs $CaCO_3$ per Acre	Phosphorus ppm	Arsenic ppm	Cadmium ppm	Chloride ppm	Chromium ppm	Cobalt ppm	Fluoride ppm	Mercury ppb
A1	0	11	0.5	0.98	2.9	0	727	10	<0.5	900	50	10	740	30
AC	11	37	0.9	0.44	2.9	0	437	20	<0.5	2400	50	11	600	60
Cr	37	49	0.9	0.41	<0.2	0	571	20	<0.5	1500	50	14	520	35

Horizon	Depth, cm		Total		Selenium Available	NH_4 Acetate Extractable		Uranium
	From	To	Antimony ppm	Vanadium ppm	ppb	Nickel ppm	Lead ppm	ppm
A1	0	11	<1	70	300	2.0	1.6	<2.0
AC	11	37	<1	70	440	1.8	2.2	<2.0
Cr	37	49	<1	70	490	2.0	2.4	<2.0

Horizon	Depth, cm		Bulk Density	Water-Holding Capacity, % (Dry Sample Wt. Basis)				Particle-Size Analysis, Wt. %			Textural Class
	From	To	g/cm^3	1/10 Bar Suction	1/3 Bar Suction	1 Bar Suction	15 Bar Suction	Sand -2.0+0.05 mm	Silt -0.05+0.002 mm	Clay -0.002 mm	
A1	0	11	0.82	39.9	30.6	23.1	14.7	19.0	68.5	12.5	Silt loam
AC	11	37	0.96	27.3	21.1	19.0	10.7	34.5	56.0	9.5	Silt loam
Cr	37	49	0.95	28.3	22.6	19.1	10.3	38.0	55.0	7.0	Silt loam

(1) Sample to extract ratio: 1 to 2.

(2) Conductivity for a saturation extract based on the 1 to 2 ratio conductivity data and the 1/3 bar water-holding capacity.

Other Series

A very limited number of samples were taken on the Rhone, Parachute, Vandamore and Irigul series. These series were located along Cathedral Bluffs. All of these series are well drained loamy soils found on upland ridges and mountain slopes. They have formed in residuum from sandstone and marlstone. The Rhone series consists of deep, noncalcareous, and neutral soils with a mollic epipedon more than 40 cm thick. Parachute soils are similar to the Rhone soils, but are slightly shallower and have a mollic epipedon about 30 cm thick. A wide variety of native shrubs and grasses are found on the Rhone and Parachute soils. The Vandamore series consists of calcareous, moderately alkaline soils that are moderately deep and do not contain a B horizon. Grasses and low shrubs dominate these soils. Irigul soils are shallow, chennery, calcareous, moderately alkaline and do not contain a B horizon. The native vegetation on these soils is dominated by shrubs.

Comparison of Soil Series

The 0-10 and the 10-50 cm sampling depths were used to compare soil traits of six soil series (Table 17). These two sampling intervals were used because the differences in soil series traits is most evident in surface and near-surface soils where pedogenetic processes have taken place. Three series found in the study area were not included due to the small sample size.

Values of pH for the six soil series were similar and had a range difference of only 0.3 units.

The Torriorthent is the only series that is saline in the surface 50 cm and none of the series are sodic. The cation exchange capacity is lowest for the Glendive and Torriorthent series, the two series with the least amount of clay. The remaining series had similar cation exchange capacities.

All series contained similar amounts of ammonium. Nitrate was unusually high in the Torriorthent series while extractable phosphorus was relatively high for the Glendive and Redcreek series. Water-soluble calcium, sodium, and sulfate were unusually high in the Torriorthent series, and available potassium was unusually low. Micronutrients did not show much variation from series to series, except for a slight copper concentration in the Torriorthent series. Of the six series examined, the Glendive series appeared to have the best balance of nutrients and would be rated as the most fertile.

Similar concentrations of trace elements were found in all soil series with the exception of the Torriorthent. This series contained generally higher

TABLE 17

Chemical and Physical Traits of the Major Soil Series(1)

Soil Series	pH in Water	pH in 0.01M $CaCl_2$	Soluble Salt Electrical Conductivity mmhos/cm (2)	Soluble Salt Electrical Conductivity mmhos/cm (3)	Sodium Water Soluble (milliequivalents/100 g)	Sodium NH_4 Acetate Soluble (milliequivalents/100 g)	Cation Exchange Capacity (milliequivalents/100 g)	Exchangeable Sodium Percentage
Glendive	8.5	7.9	0.82	3.4	0.76	2.33	29.4	5.2
Redcreek	8.2	7.6	0.55	2.4	0.45	1.51	39.3	2.7
Yamac	8.3	7.5	0.39	1.6	0.42	1.59	42.3	2.9
Rentsac	8.2	7.6	0.42	1.6	0.33	1.50	42.2	2.8
Torriorthent	8.3	8.1	2.21	8.8	3.17	5.46	25.3	9.1
Piceance	8.4	7.8	0.31	1.3	0.39	1.35	40.7	2.4

					Water Soluble					DTPA Extractable			
Soil Series	Ammonium ppm	Nitrate ppm	Phosphorus $NaHCO_3$ Extractable ppm	Potassium Available ppm	Magnesium ppm	Calcium ppm	Potassium ppm	Sulfate ppm	Boron ppm	Copper ppm	Manganese ppm	Iron ppm	Zinc ppm
Glendive	10.1	4.8	23.0	646.1	15.8	65.1	26.8	295.7	0.7	1.6	30.7	95.8	1.7
Redcreek	9.8	1.8	23.1	348.3	12.4	48.6	10.6	190.7	0.7	1.2	49.0	115.0	1.5
Yamac	9.2	1.8	12.3	489.4	7.7	33.6	7.6	184.2	0.5	1.4	34.9	97.8	1.1
Rentsac	9.5	2.3	11.3	264.0	6.3	41.4	5.5	133.5	0.6	1.7	37.2	104.0	1.4
Torriorthent	11.1	10.3	7.3	151.1	32.0	225.4	8.8	1246.0	0.7	3.1	20.8	76.3	1.2
Piceance	10.2	1.5	8.7	412.7	7.4	41.5	7.8	245.9	0.6	1.8	44.3	83.3	1.4

					Total							
Soil Series	Molybdenum Anion Exchangeable ppm	Organic Matter %	Gypsum Requirement MEQ/100 g	Lime Requirement lb $CaCO_3$/acre	Phosphorus ppm	Arsenic ppm	Cadmium ppm	Chloride ppm	Chromium ppm	Cobalt ppm	Fluoride ppm	Mercury ppb
Glendive	0.4	3.4	0.3	0	533.1	7.7	0.5	935.7	47.3	7.5	585.7	18.8
Redcreek	0.3	3.5	0.3	0	526.0	5.7	0.5	836.7	45.0	8.1	386.3	16.0
Yamac	0.2	2.3	0.3	0	711.2	6.3	0.5	700.0	48.4	9.4	368.8	12.5
Rentsac	0.3	4.1	0.3	0	503.6	9.1	0.5	874.6	42.9	7.7	478.8	23.7
Torriorthent	0.4	2.0	0.4	0	455.1	14.3	0.5	1128.6	36.4	7.2	644.3	33.9
Piceance	0.3	2.7	0.2	0	572.9	8.1	0.5	769.2	43.1	8.2	433.1	15.1

	Total			NH_4 Acetate Extractable		Background Radioactivity				
Soil Series	Antimony ppm	Vanadium ppm	Selenium Available ppb	Nickel ppm	Lead ppm	Uranium ppm	Equivalent Uranium ppm	Equivalent Thorium ppm	Potassium Radioactivity %	$Radium^{226}$ Picocuries/g
Glendive	1.0	58.9	29.3	0.8	1.5	2.1	2.6	9.5	2.4	0.9
Redcreek	1.0	52.8	12.0	0.9	1.5	2.3	2.2	12.6	2.7	0.8
Yamac	1.0	61.6	11.3	0.8	1.1	2.1	2.3	11.5	2.7	0.8
Rentsac	1.1	56.8	18.0	0.8	1.5	2.2	2.9	9.6	2.4	1.1
Torriorthent	1.0	63.9	70.7	1.4	2.2	2.2	2.6	8.0	2.4	0.8
Piceance	1.0	62.7	13.9	0.9	1.3	2.1	3.1	11.3	2.5	1.0

	Water-Holding Capacity, % (Dry Sample Wt. Basis)		Particle-Size Analysis, Wt. %			
Soil Series	1/3 Bar Suction	15 Bar Suction	Sand -2.0 +0.05 mm	Silt -0.05 +0.002 mm	Clay -0.002 mm	Textural Class
Glendive	23.9	11.8	42.0	47.2	10.8	Loam
Redcreek	22.1	12.1	47.6	40.4	12.0	Loam
Yamac	23.9	11.1	38.8	45.5	15.8	Loam
Rentsac	28.0	14.1	37.1	48.7	14.2	Loam
Torriorthent	25.1	11.1	30.8	58.5	10.8	Silt loam
Piceance	25.2	12.6	31.9	51.6	16.5	Silt loam

(1) Individual parameters express the mean value of the 0 to 10 plus the 10 to 50 cm depths.
(2) Sample to extract ratio: 1 to 2.
(3) Conductivity for a saturation extract based on 1 to 2 ratio conductivity data and the 1/3 bar water-holding capacity.

concentrations of trace elements, although none of the trace elements examined were outside of the range considered normal and nontoxic for soils.

Values of background radiation were very similar for all series. Physical traits showed little variation in both water-holding capacity and texture.

SOIL MATERIAL SUITABLE FOR USE IN RECLAMATION

In most areas of the United States, state reclamation laws require that "topsoil" be applied to areas disturbed by mining. The definition of topsoil varies from state to state, and for the purposes of this study, topsoil is defined as natural soil material having chemical and physical properties suitable for use as a plant-growth medium. The sampling regime used in this study restricts the depth of topsoil to no more than 150 cm.

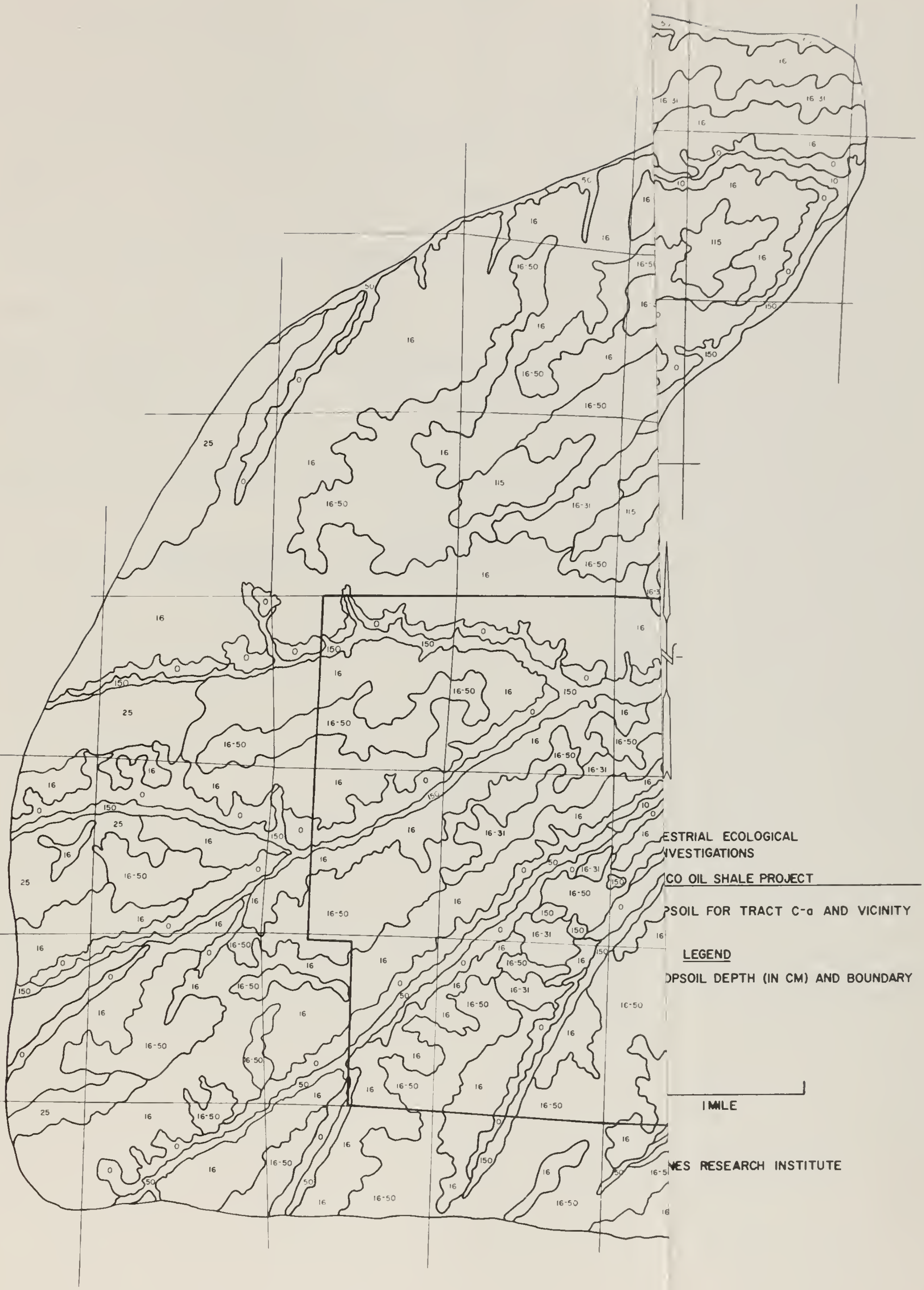
Soil properties most frequently limiting the use of soil for topsoil are rock, salinity and excessive sodium (sodic). Material with an electrical conductivity of 8.0 mmhos/cm or greater were considered unsuitable for use as topsoil. Salinity is especially restrictive during plant germination and early growth. If such material were used as topsoil, it is probable that eventually plants would become established (as evidenced by undisturbed areas where the surface soil has an electrical conductivity of 8.0 mmhos/cm or more), but the time span may not be acceptable. Sodic soils restrict plant germination and growth and although this restriction may not be great, it could complicate and delay revegetation. A certain amount of rock can be tolerated in topsoil, but excessive amounts present problems in the movement,

grading, and seeding of topsoiled spoils.

In the process of removing, storing, and respreading topsoil, considerable mixing will take place and soils with adverse traits may be diluted to such an extent that the mixture of soils will be suitable for use as topsoil. However, such mixing and the resulting dilution is not considered here and must wait until the areas to be disturbed are accurately defined and examined in more detail.

The soil series was used as the basis for determining and mapping the depth of topsoil (Figure 3). Tables 18 through 26 give the chemical and the physical traits of each sampling interval of each series. In addition to these data, the depth to rock was also used to determine topsoil depth. Before topsoil is removed from a specific area, more soil testing is suggested. Topsoil depth is quite variable and the average values given in Figure 3 are unlikely to be precise enough for adequate topsoil removal from relatively small areas. Such areas should be intensively sampled to determine depth to rock and laboratory analyses should be conducted to determine salinity, ESP, and available selenium. It would not be necessary to examine other soil traits as the data previously presented shows that other soil traits restrictive to plant growth are not to be expected.

Following is a discussion of the topsoil depth found within each soil series.



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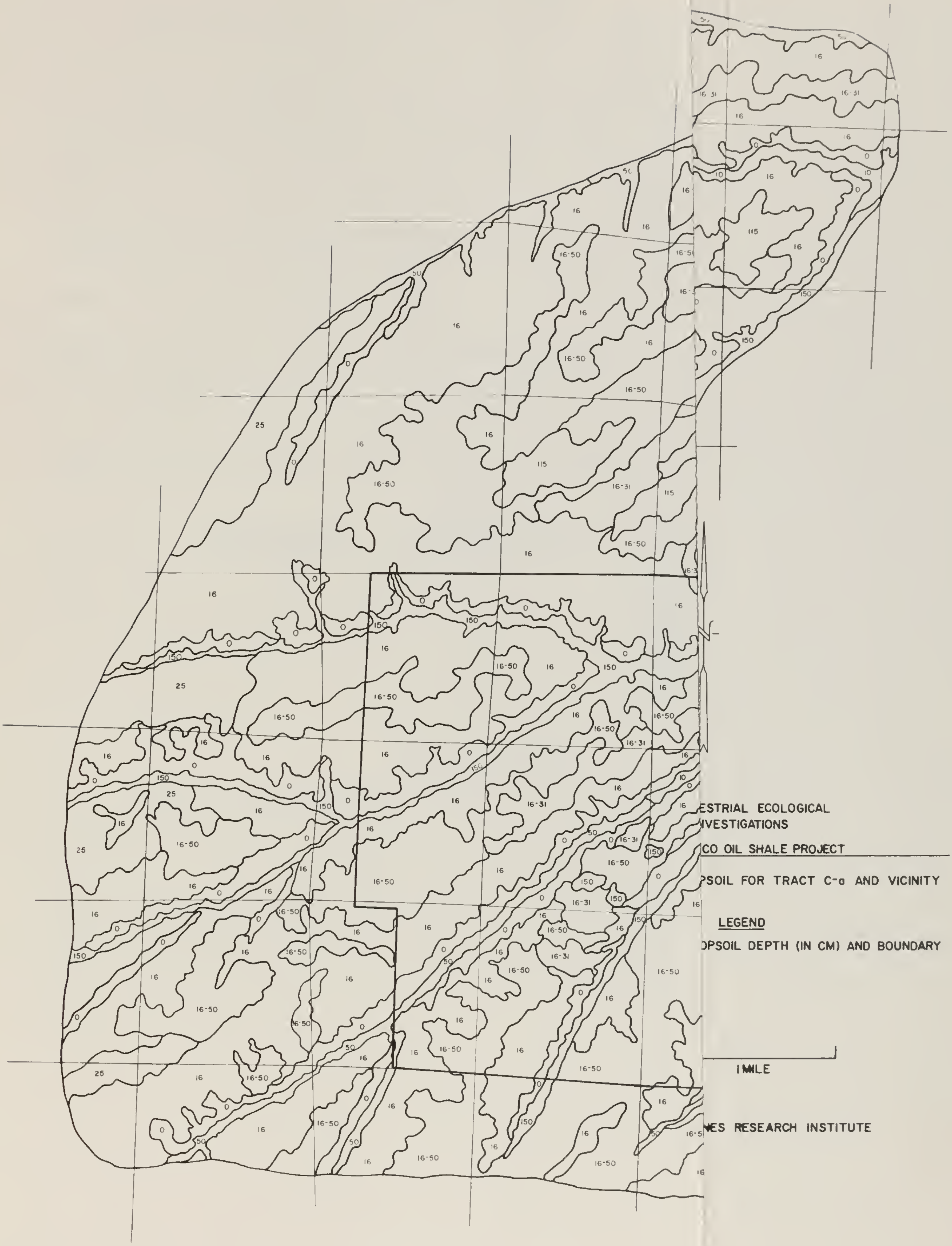
PSOIL FOR TRACT C-a AND VICINITY

LEGEND

PSOIL DEPTH (IN CM) AND BOUNDARY

NES RESEARCH INSTITUTE



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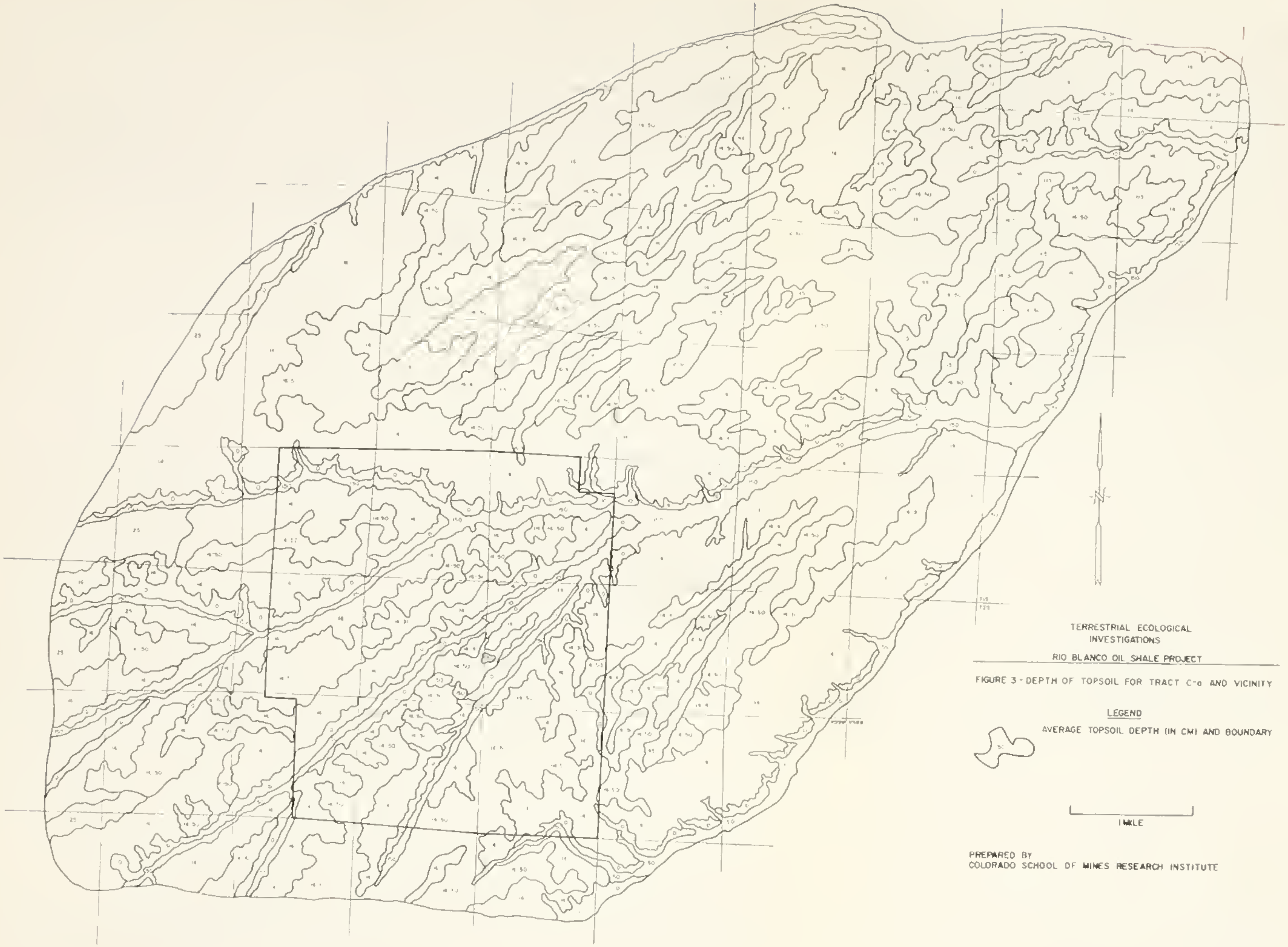
PSOIL FOR TRACT C-a AND VICINITY

LEGEND

OPSOIL DEPTH (IN CM) AND BOUNDARY

NES RESEARCH INSTITUTE



TERRESTRIAL ECOLOGICAL
INVESTIGATIONS

RIO BLANCO OIL SHALE PROJECT

FIGURE 3 - DEPTH OF TOPSOIL FOR TRACT C-a AND VICINITY

LEGEND

AVERAGE TOPSOIL DEPTH (IN CM) AND BOUNDARY

1 MILE

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Havre Series

The Havre profile is saline throughout, although only in the 10-50 cm sampling interval is the degree of salinity high enough to render the material unsuitable for use as topsoil (Table 18). A more serious limitation is found in the concentration of available selenium. The selenium content of all four sampling depths was relatively high and may pose a health hazard to livestock. However, not all Havre sites are saline and high in selenium, and if the problem areas can be avoided, the remaining soil in the Havre series would be well suited for use as topsoil down to a depth of at least 150 cm. Sites not suited for use as topsoil are:

Sampling Site	Depth of Restriction, cm	Restricting Trait
44	50	Selenium Sodic Saline
66	0	Saline Selenium

Glendive Series

Table 19 indicates that, on the average, the Glendive series is suitable for use as topsoil down to a depth of at least 150 cm. These soils were essentially free of rock. However, some sampling sites in the Glendive series contained material not suited for use as topsoil. These sites are:

Sampling Site	Depth of Restriction, cm	Restricting Trait
41	50	Sodic
42	50	Sodic Saline
45	10	Sodic Saline
61	50	Sodic Saline Selenium
73	10	Saline
74	50	Sodic
98	0	Saline

Castner Series

Chemical and physical traits of the Castner series (Table 20) indicate that these soils are fertile and free of toxicants, and are well suited for use as topsoil. Individual sampling sites with adverse traits were not found. Rock is a limiting factor in the use of this soil, and only the surface 25 cm can be used as topsoil.

Rentsac Series

The Rentsac series is sodic below the 50 cm depth and would not serve well as topsoil. The chemical properties of the surface 50 cm are nonrestrictive to plant growth (Table 21). However, considerable rock is found in the 10-50 cm interval. Depth to rock ranges from 5 to 50 cm and averages 16 cm. Thus, only the surface 16 cm of the Rentsac series is suitable for use as topsoil. Individual sites where the surface 16 cm has undesirable chemical properties were not found.

Piceance Series

On the basis of the average chemical traits of this series (Table 22), only the 100-150 cm depth would be unsuitable for use as topsoil. This depth is both saline and sodic. Depth to rock averages 50 cm and ranges from 30 to 100 cm. Within the Piceance series no sites were found where the chemical traits of the surface 50 cm of soil were unsuited for use as topsoil. Therefore, 50 cm of topsoil is available, on the average, in the Piceance series.

Redcreek Series

The chemical properties of the Redcreek series, as presented in Table 23, would not restrict the use of these soils as a source of topsoil in the reclamation program. Depth to rock ranges from 8 to 50 cm and averages 31 cm. Thus, suitable topsoil is available to a depth of 31 cm except for the sites listed below.

Sampling Site	Depth of Restriction, cm	Restricting Trait
99	0	Salinity
101	0	Salinity

Yamac Series

Chemical traits which would render some portions of the average Yamac profile unsuitable for topsoil were not found (Table 24). Depth to rock averaged 115 cm and ranged from 40 cm on Mesa 84 to 150 cm just east of Tract C-a. However, 115 cm of topsoil is not available at all sites. Sites where the topsoil would be less are as follows:

Sampling Site	Depth of Restriction, cm	Restricting Trait
50	100	Salinity
53	10	Salinity

Rivra Series

Although saline material was found at 100-150 cm (Table 25), the degree of salinity was low and would not restrict the use of this material as topsoil. The Rivra series is quite sandy and, with the exception of the surface sampling interval, may not have the potential to retain sufficient water for normal plant growth. In addition to being droughty, sandy material retains fertilizer poorly and is vulnerable to wind erosion. The 0-10 cm sampling interval is suitable for use as topsoil, but the remaining material is too sandy for use as topsoil.

Torriorthent Series

Based on the average chemical traits (Table 26), the degree of salinity of this series precludes its use as topsoil. In addition, rock is found within the first 10 cm.

Fertilization of Topsoil

For the soil material considered suitable for use as topsoil, both nitrogen and phosphorus averaged 13 ppm. Plants should have an adequate supply of these two macronutrients at all times, but an adequate supply is especially critical during the early stages of revegetation. The nitrogen concentration is relatively low and the application of approximately 30 pounds per acre of elemental nitrogen is recommended. The concentration of plant-

TABLE 18

Chemical and Physical Traits of the Havre Series(1)

Depth, cm		pH in	pH in	Soluble Salt Electrical Conductivity	Soluble Salt Electrical Conductivity	Sodium Water Soluble	Sodium NH_4 Acetate Soluble	Cation Exchange Capacity	Exchangeable Sodium Percentage
From	To	Water	0.01M $CaCl_2$	mmhos/cm (2)	mmhos/cm (3)	(milliequivalents/100 g)			
0	10	8.4	7.8	1.92	5.0	1.48	2.88	41.5	3.4
10	50	8.4	8.1	3.08	8.3	2.96	4.10	37.3	3.1
50	100	8.5	8.2	1.84	5.9	1.86	4.00	29.9	7.2
100	150	8.7	8.2	2.40	7.6	1.79	4.67	28.8	10.0

Depth, cm		Ammonium	Nitrate	Phosphorus $NaHCO_3$ Extractable	Potassium Available	Water Soluble					DTPA Extractable			
From	To	ppm	ppm	ppm	ppm	Magnesium ppm	Calcium ppm	Potassium ppm	Sulfate ppm	Boron ppm	Copper ppm	Manganese ppm	Iron ppm	Zinc ppm
0	10	19.3	2.7	41.0	1246.1	63.4	121.5	59.2	427.0	0.8	2.3	64.5	128.0	3.2
10	50	9.5	2.7	12.5	706.3	78.8	134.4	52.4	1709.3	0.8	2.1	37.8	81.3	3.6
50	100	15.7	24.8	15.8	571.0	44.3	76.2	25.1	547.5	0.9	2.1	32.3	79.0	1.5
100	150	11.0	5.7	9.0	711.7	68.5	91.2	27.1	728.0	0.7	2.1	19.0	42.7	1.3

Depth, cm		Molybdenum Anion Exchangeable	Organic Matter	Gypsum Requirement	Lime Requirement	Total							
From	To	ppm	%	MEQ/100 g	lb $CaCO_3$/acre	Phosphorus ppm	Arsenic ppm	Cadmium ppm	Chloride ppm	Chromium ppm	Cobalt ppm	Fluoride ppm	Mercury ppb
0	10	0.4	6.3	0.2	0	719.5	8.8	0.5	825.0	40.0	7.8	587.5	20.0
10	50	0.6	3.8	0.4	0	676.0	7.5	0.5	825.0	41.3	7.8	580.0	16.3
50	100	0.6	2.4	0.2	0	669.5	5.0	0.5	950.0	41.3	8.5	550.0	15.0
100	150	0.6	1.7	0.4	0	708.7	8.3	0.5	833.3	43.3	5.7	573.3	15.0

Depth, cm		Total		Selenium	NH_4 Acetate Extractable		Background Radioactivity				
From	To	Antimony ppm	Vanadium ppm	Available ppb	Nickel ppm	Lead ppm	Uranium ppm	Equivalent Uranium ppm	Equivalent Thorium ppm	Potassium Radioactivity %	$Radium^{226}$ Picocuries/g
0	10	1.0	67.5	615.0	1.2	1.9	2.0	2.2	1.1	2.5	0.5
10	50	1.0	62.5	670.0	1.2	1.9	2.0	3.0	0.9	2.3	1.0
50	100	1.0	65.0	645.0	1.1	1.8	2.0	2.3	1.0	2.3	0.9
100	150	1.0	70.0	650.0	1.0	1.7	2.0	3.0	0.9	2.2	1.0

Depth, cm		Water-Holding Capacity, % (Dry Sample Wt. Basis)		Particle-Size Analysis, Wt. %			
From	To	1/3 Bar Suction	15 Bar Suction	Sand -2.0 +0.05 mm	Silt -0.05 +0.002 mm	Clay -0.002 mm	Textural Class
0	10	38.1	17.7	18.0	62.1	19.9	Silt loam
10	50	36.9	16.3	11.5	69.5	19.0	Silt loam
50	100	31.3	13.5	27.3	55.9	16.9	Silt loam
100	150	31.6	15.7	21.0	59.3	19.7	Silt loam

(1) n = 4 for the 0-10, 10-50, and 50-100 cm sampling depths; n = 3 for the 100-150 cm depth.

(2) Sample to extract ratio: 1 to 2.

(3) Conductivity for a saturation extract based on 1 to 2 ratio conductivity data and the 1/3 bar water-holding capacity.

TABLE 19

Chemical and Physical Traits of the Glendive Series(1)

Depth, cm		pH in Water	pH in 0.01M CaCl$_2$	Soluble Salt Electrical Conductivity mmhos/cm (2)	Soluble Salt Electrical Conductivity mmhos/cm (3)	Sodium Water Soluble	Sodium NH$_4$ Acetate Soluble	Cation Exchange Capacity	Exchangeable Sodium Percentage
From	To					(milliequivalents/100 g)			
0	10	8.4	7.8	0.70	2.8	0.61	1.70	30.5	3.8
10	50	8.5	8.0	0.94	4.1	0.90	2.96	28.3	7.3
50	100	8.5	8.0	1.29	5.2	1.69	4.90	28.9	11.1
100	150	8.5	8.1	1.94	7.7	1.94	4.38	27.7	8.8

Depth, cm		Ammonium	Nitrate	Phosphorus NaHCO$_3$ Extractable	Potassium Available	Water Soluble					DTPA Extractable			
From	To	ppm	ppm	ppm	ppm	Magnesium ppm	Calcium ppm	Potassium ppm	Sulfate ppm	Boron ppm	Copper ppm	Manganese ppm	Iron ppm	Zinc ppm
0	10	11.2	3.6	33.9	826.8	10.5	52.3	35.6	240.1	0.8	1.6	35.7	101.6	2.0
10	50	9.1	6.0	12.1	465.4	21.0	77.9	18.1	350.7	0.8	1.6	25.6	90.0	1.4
50	100	8.4	22.1	12.4	429.6	32.4	67.3	19.3	391.6	0.7	1.9	25.5	91.7	1.5
100	150	6.8	55.3	11.9	461.2	35.8	85.0	17.8	411.8	0.7	2.0	21.3	86.5	1.3

Depth, cm		Molybdenum Anion Exchangeable	Organic Matter	Gypsum Requirement	Lime Requirement	Total							
From	To	ppm	%	MEQ/100 g	lb CaCO$_3$/ acre	Phosphorus ppm	Arsenic ppm	Cadmium ppm	Chloride ppm	Chromium ppm	Cobalt ppm	Fluoride ppm	Mercury ppb
0	10	0.4	4.2	0.2	0	542.8	7.5	0.5	914.3	47.1	6.8	561.4	18.9
10	50	0.4	2.6	0.3	0	523.4	7.9	0.5	957.1	47.5	8.2	610.0	18.6
50	100	0.4	2.2	0.5	0	518.5	7.5	0.5	1157.1	47.1	7.1	608.6	17.9
100	150	0.4	1.8	0.5	0	553.7	9.2	0.5	1153.9	48.1	7.8	639.2	20.0

Depth, cm		Total		Selenium Available	NH$_4$ Acetate Extractable		Background Radioactivity				
From	To	Antimony ppm	Vanadium ppm	ppb	Nickel ppm	Lead ppm	Uranium ppm	Equivalent Uranium ppm	Equivalent Thorium ppm	Potassium Radioactivity %	Radium^{226} Picocuries/ g
0	10	1.0	57.5	27.9	0.7	1.5	2.2	2.5	9.9	2.5	0.8
10	50	1.0	60.4	30.7	0.8	1.5	2.0	2.8	9.2	2.4	1.0
50	100	1.0	59.6	41.4	0.8	1.5	2.1	2.7	9.8	2.4	0.9
100	150	1.0	63.9	129.2	0.8	1.5	2.2	2.5	10.1	2.4	0.8

Depth, cm		Water-Holding Capacity, % (Dry Sample Wt. Basis)		Particle-Size Analysis, Wt. %			
From	To	1/3 Bar Suction	15 Bar Suction	Sand -2.0 +0.05 mm	Silt -0.05 +0.002 mm	Clay -0.002 mm	Textural Class
0	10	24.8	12.0	43.4	46.4	10.2	Loam
10	50	23.1	11.6	40.6	48.0	11.5	Loam
50	100	24.9	12.2	38.4	48.6	13.0	Loam
100	150	25.3	11.7	38.4	48.0	13.7	Loam

(1) n = 14 for the 0-10, 10-50, and 50-100 cm sampling depths; n = 13 for the 100-150 cm depth.

(2) Sample to extract ratio: 1 to 2.

(3) Conductivity for a saturation extract based on 1 to 2 ratio conductivity data and the 1/3 bar water-holding capacity.

TABLE 20

Chemical and Physical Traits of the Castner Series[1]

Depth, cm From	Depth, cm To	pH in Water	pH in 0.01M $CaCl_2$	Soluble Salt Electrical Conductivity mmhos/cm (2)	Soluble Salt Electrical Conductivity mmhos/cm (3)	Sodium Water Soluble (milliequivalents/100 g)	Sodium NH_4 Acetate Soluble (milliequivalents/100 g)	Cation Exchange Capacity (milliequivalents/100 g)	Exchangeable Sodium Percentage
0	10	8.1	7.5	0.27	0.8	0.05	0.34	65.4	0.4
10	50	8.3	7.8	0.26	0.8	0.06	0.31	64.2	0.4
50	100	8.6	7.5	0.24	0.7	0.08	0.72	43.3	1.5
100	150	8.8	8.3	0.22	0.7	0.09	0.66	43.2	1.3

Depth, cm				Phosphorus	Potassium	Water Soluble					DTPA Extractable			
From	To	Ammonium ppm	Nitrate ppm	$NaHCO_3$ Extractable ppm	Available ppm	Magnesium ppm	Calcium ppm	Potassium ppm	Sulfate ppm	Boron ppm	Copper ppm	Manganese ppm	Iron ppm	Zinc ppm
0	10	15.4	4.9	12.7	893.3	4.1	43.8	20.1	68.3	0.6	1.7	65.7	162.7	2.3
10	50	13.6	4.7	7.3	540.0	4.4	48.8	10.6	47.7	0.5	2.0	46.3	150.7	1.4
50	100	7.4	2.4	6.7	126.7	6.3	35.5	2.4	47.3	0.5	1.6	16.3	84.7	0.8
100	150	2.6	0.2	13.0	140.0	8.0	23.9	0.9	125.0	0.5	1.6	10.0	56.0	0.8

Depth, cm		Molybdenum	Organic	Gypsum	Lime	Total							
From	To	Anion Exchangeable ppm	Matter %	Requirement MEQ/100 g	Requirement lb $CaCO_3$/acre	Phosphorus ppm	Arsenic ppm	Cadmium ppm	Chloride ppm	Chromium ppm	Cobalt ppm	Fluoride ppm	Mercury ppb
0	10	0.4	6.3	0.5	0	569.3	10.0	0.5	533.3	41.7	9.0	440.0	15.0
10	50	0.5	4.1	0.3	0	582.7	13.3	0.5	733.3	42.0	9.0	396.7	16.7
50	100	0.1	2.6	0.2	0	422.7	10.0	0.5	1133.3	33.3	7.7	403.3	23.3
100	150	0.7	0.6	0.2	0	955.0	5.0	0.5	500.0	40.0	8.0	460.0	15.0

Depth, cm		Total		Selenium	NH_4 Acetate Extractable		Background Radioactivity				
From	To	Antimony ppm	Vanadium ppm	Available ppb	Nickel ppm	Lead ppm	Uranium ppm	Equivalent Uranium ppm	Equivalent Thorium ppm	Potassium Radioactivity %	Radium226 Picocuries/g
0	10	1.0	66.7	16.7	1.0	0.9	2.0	2.7	1.0	2.7	0.7
10	50	1.0	58.3	13.3	1.0	1.0	2.0	2.3	1.1	2.2	0.7
50	100	1.0	48.3	10.0	0.9	0.7	2.3	1.3	0.5	2.0	0.8
100	150	1.0	55.0	10.0	1.0	0.7	2.0	3.0	7.0	3.3	1.0

Depth, cm		Water-Holding Capacity, % (Dry Sample Wt. Basis)		Particle-Size Analysis, Wt. %			
From	To	1/3 Bar Suction	15 Bar Suction	Sand -2.0 +0.05 mm	Silt -0.05 +0.002 mm	Clay -0.002 mm	Textural Class
0	10	32.4	16.5	20.3	58.0	21.7	Silt loam
10	50	34.1	16.5	19.5	57.3	23.2	Silt loam
50	100	36.1	15.4	25.5	56.7	17.8	Silt loam
100	150	32.0	17.9	32.0	52.5	15.5	Silt loam

(1) n = 3 for the 0-10, 10-50, and 50-100 cm sampling depths; n = 1 for the 100-150 cm depth.

(2) Sample to extract ratio: 1 to 2.

(3) Conductivity for a saturation extract based on 1 to 2 ratio conductivity data and the 1/3 bar water-holding capacity.

TABLE 21

Chemical and Physical Traits of the Rentsac Series(1)

Depth, cm		pH in	pH in	Soluble Salt Electrical Conductivity	Soluble Salt Electrical Conductivity	Sodium Water Soluble	Sodium NH$_4$ Acetate Soluble	Cation Exchange Capacity	Exchangeable Sodium
From	To	Water	0.01M CaCl$_2$	mmhos/cm (2)	mmhos/cm (3)	(milliequivalents/100 g)			Percentage
0	10	8.1	7.5	0.44	1.7	0.27	1.42	45.1	2.7
10	50	8.3	7.8	0.41	1.5	0.38	1.57	39.4	3.0
50	100	9.1	8.2	0.89	3.8	1.49	5.97	25.2	17.8
100	150	8.9	8.2	0.99	4.6	1.61	5.80	21.8	19.2

Depth, cm				Phosphorus NaHCO$_3$		Water Soluble					DTPA Extractable			
From	To	Ammonium ppm	Nitrate ppm	Extractable ppm	Potassium Available ppm	Magnesium ppm	Calcium ppm	Potassium ppm	Sulfate ppm	Boron ppm	Copper ppm	Manganese ppm	Iron ppm	Zinc ppm
0	10	10.4	2.4	13.7	367.6	6.0	42.1	6.6	148.8	0.6	1.3	46.6	103.3	1.7
10	50	8.6	2.1	8.9	160.4	6.6	40.6	4.4	118.2	0.6	2.1	27.7	104.8	1.2
50	100	8.2	1.4	5.6	135.0	5.5	16.7	6.5	170.9	0.7	1.7	19.6	101.5	1.3
100	150	5.1	0.7	7.9	130.0	5.9	12.3	6.5	189.4	0.6	2.0	18.1	82.8	0.9

Depth, cm		Molybdenum Anion	Organic	Gypsum	Lime Requirement	Total							
From	To	Exchangeable ppm	Matter %	Requirement MEQ/100 g	lb CaCO$_3$/acre	Phosphorus ppm	Arsenic ppm	Cadmium ppm	Chloride ppm	Chromium ppm	Cobalt ppm	Fluoride ppm	Mercury ppb
0	10	0.3	4.8	0.2	0	558.0	8.8	0.5	893.2	45.6	8.0	465.6	20.4
10	50	0.2	3.5	0.3	0	449.2	9.4	0.5	856.0	40.2	7.4	492.0	27.0
50	100	0.2	1.0	0.7	0	407.1	8.0	0.5	1020.0	40.0	6.4	480.7	19.3
100	150	0.2	0.9	0.8	0	386.0	6.3	0.5	1062.5	41.9	6.3	580.0	21.3

Depth, cm		Total		Selenium	NH$_4$ Acetate Extractable		Background Radioactivity				
From	To	Antimony ppm	Vanadium ppm	Available ppb	Nickel ppm	Lead ppm	Uranium ppm	Equivalent Uranium ppm	Equivalent Thorium ppm	Potassium Radioactivity %	Radium226 Picocuries/g
0	10	1.1	58.8	15.2	0.8	1.4	2.1	2.9	10.2	2.6	1.0
10	50	1.1	54.8	20.8	0.9	1.5	2.4	2.9	9.0	2.2	1.1
50	100	1.0	49.0	27.3	0.6	1.2	2.4	3.3	12.2	2.2	1.0
100	150	1.0	45.0	20.0	0.4	1.2	3.0	3.6	9.9	2.3	1.2

Depth, cm		Water-Holding Capacity, % (Dry Sample Wt. Basis)		Particle-Size Analysis, Wt. %			
From	To	1/3 Bar Suction	15 Bar Suction	Sand -2.0 +0.05 mm	Silt -0.05 +0.002 mm	Clay -0.002 mm	Textural Class
0	10	26.3	13.6	37.6	47.7	14.7	Loam
10	50	29.6	14.5	36.5	49.8	13.7	Loam
50	100	23.3	9.9	49.1	41.4	9.5	Loam
100	150	21.3	9.3	49.8	41.3	8.9	Loam

(1) n = 25 for the 0-10 and 10-50 cm sampling depth; n = 15 for the 50-100 cm depth; n = 8 for the 100-150 cm depth.

(2) Sample to extract ratio: 1 to 2.

(3) Conductivity for a saturation extract based on 1 to 2 ratio conductivity data and the 1/3 bar water-holding capacity.

TABLE 22

Chemical and Physical Traits of the Piceance Series(1)

Depth, cm From	To	pH in Water	pH in 0.01M $CaCl_2$	Soluble Salt Electrical Conductivity mmhos/cm (2)	Soluble Salt Electrical Conductivity mmhos/cm (3)	Sodium Water Soluble (milliequivalents/100 g)	Sodium NH_4 Acetate Soluble (milliequivalents/100 g)	Cation Exchange Capacity (milliequivalents/100 g)	Exchangeable Sodium Percentage
0	10	8.4	7.7	0.32	1.4	0.19	1.13	40.6	2.3
10	50	8.5	7.8	0.29	1.1	0.60	1.58	40.7	2.4
50	100	8.8	8.0	1.11	3.8	1.99	5.28	34.5	9.5
100	150	9.0	8.2	2.97	11.8	4.49	10.25	33.4	17.2

						Water Soluble					DTPA Extractable			
Depth, cm From	To	Ammonium ppm	Nitrate ppm	Phosphorus $NaHCO_3$ Extractable ppm	Potassium Available ppm	Magnesium ppm	Calcium ppm	Potassium ppm	Sulfate ppm	Boron ppm	Copper ppm	Manganese ppm	Iron ppm	Zinc ppm
0	10	11.1	1.8	10.6	483.9	5.4	36.2	10.4	204.5	0.6	1.8	51.7	75.9	1.4
10	50	9.5	1.1	6.8	341.5	9.3	46.8	5.3	287.3	0.5	1.9	36.9	90.7	1.3
50	100	6.7	4.2	6.8	199.6	20.1	52.9	5.4	494.2	0.6	2.1	25.2	84.3	1.1
100	150	8.7	1.3	10.2	230.0	30.7	122.6	9.6	1125.0	0.6	1.8	22.3	141.3	1.5

						Total							
Depth, cm From	To	Molybdenum Anion Exchangeable ppm	Organic Matter %	Gypsum Requirement MEQ/100 g	Lime Requirement lb $CaCO_3$/acre	Phosphorus ppm	Arsenic ppm	Cadmium ppm	Chloride ppm	Chromium ppm	Cobalt ppm	Fluoride ppm	Mercury ppb
0	10	0.3	3.2	0.3	0	629.4	6.5	0.5	815.4	44.2	8.5	422.3	13.9
10	50	0.3	2.3	0.2	0	516.4	9.6	0.5	723.1	41.9	7.9	443.9	16.5
50	100	0.2	1.6	0.3	0	593.5	12.1	0.5	1091.7	38.8	8.3	528.3	21.7
100	150	0.4	0.9	0.9	0	551.5	7.5	0.5	1266.7	44.2	9.5	536.7	18.3

		Total			NH_4 Acetate Extractable		Background Radioactivity				
Depth, cm From	To	Antimony ppm	Vanadium ppm	Selenium Available ppb	Nickel ppm	Lead ppm	Uranium ppm	Equivalent Uranium ppm	Equivalent Thorium ppm	Potassium Radioactivity %	$Radium^{226}$ Picocuries/g
0	10	1.0	63.5	13.1	0.8	1.3	2.2	2.9	11.8	2.6	0.9
10	50	1.0	61.9	14.6	0.9	1.3	2.1	3.3	10.8	2.4	1.1
50	100	1.0	57.9	21.7	0.9	1.3	2.2	3.0	10.8	2.4	0.9
100	150	1.2	64.2	31.7	1.0	1.2	3.0	3.5	14.0	2.7	1.1

		Water-Holding Capacity, % (Dry Sample Wt. Basis)		Particle-Size Analysis, Wt. %			
Depth, cm From	To	1/3 Bar Suction	15 Bar Suction	Sand -2.0 +0.05 mm	Silt -0.05 +0.002 mm	Clay -0.002 mm	Textural Class
0	10	24.3	12.1	33.0	50.7	16.4	Silt loam
10	50	26.2	13.2	30.7	52.6	16.7	Silt loam
50	100	29.3	13.8	31.5	52.4	16.1	Silt loam
100	150	25.2	11.2	41.8	45.1	13.2	Loam

(1) n = 13 for the 0-10 and 10-50 cm sampling depth; n = 12 for the 50-100 cm depth; n = 6 for the 100-150 cm depth.
(2) Sample to extract ratio: 1 to 2.
(3) Conductivity for a saturation extract based on 1 to 2 ratio conductivity data and the 1/3 bar water-holding capacity.

TABLE 23

Chemical and Physical Traits of the Redcreek Series(1)

Depth, cm From	Depth, cm To	pH in Water	pH in 0.01M $CaCl_2$	Soluble Salt Electrical Conductivity mmhos/cm (2)	Soluble Salt Electrical Conductivity mmhos/cm (3)	Sodium Water Soluble (milliequivalents/100 g)	Sodium NH_4 Acetate Soluble (milliequivalents/100 g)	Cation Exchange Capacity (milliequivalents/100 g)	Exchangeable Sodium Percentage
0	10	8.0	7.4	0.60	2.8	0.41	1.30	40.9	2.3
10	50	8.4	7.8	0.49	2.2	0.49	1.72	37.7	3.4
50	100	8.9	8.2	0.87	4.7	1.37	4.31	29.0	10.1
100	150	8.8	8.1	1.09	5.7	1.65	5.25	26.0	13.8

Depth, cm						Water Soluble					DTPA Extractable			
From	To	Ammonium ppm	Nitrate ppm	Phosphorus $NaHCO_3$ Extractable ppm	Potassium Available ppm	Magnesium ppm	Calcium ppm	Potassium ppm	Sulfate ppm	Boron ppm	Copper ppm	Manganese ppm	Iron ppm	Zinc ppm
0	10	10.8	2.5	34.3	456.7	13.8	46.3	14.2	233.2	0.8	1.2	59.5	117.7	1.8
10	50	8.8	1.2	12.0	240.0	11.0	50.9	7.0	148.1	0.7	1.1	38.5	112.3	1.3
50	100	4.0	1.0	8.6	160.0	9.5	26.9	5.1	163.4	0.7	1.0	29.6	136.9	1.4
100	150	4.7	1.2	8.3	166.7	14.7	30.8	5.1	217.0	0.6	1.1	30.7	121.3	1.5

Depth, cm						Total							
From	To	Molybdenum Anion Exchangeable ppm	Organic Matter %	Gypsum Requirement MEQ/100 g	Lime Requirement lb $CaCO_3$/acre	Phosphorus ppm	Arsenic ppm	Cadmium ppm	Chloride ppm	Chromium ppm	Cobalt ppm	Fluoride ppm	Mercury ppb
0	10	0.4	4.6	0.3	0	514.6	5.7	0.5	826.7	46.0	8.6	368.7	14.7
10	50	0.2	2.5	0.4	0	537.4	5.7	0.5	846.7	44.0	7.6	404.0	17.3
50	100	0.2	1.8	0.4	0	452.9	5.0	0.5	971.4	47.1	7.7	568.6	22.1
100	150	0.2	1.0	0.5	0	529.7	5.0	0.5	900.0	53.3	8.7	373.3	18.3

Depth, cm		Total			NH_4 Acetate Extractable		Background Radioactivity				
From	To	Antimony ppm	Vanadium ppm	Selenium Available ppb	Nickel ppm	Lead ppm	Uranium ppm	Equivalent Uranium ppm	Equivalent Thorium ppm	Potassium Radioactivity %	Radium^{226} Picocuries/g
0	10	1.0	53.3	12.0	0.8	1.4	2.3	2.3	12.5	2.7	0.8
10	50	1.0	52.3	12.0	1.0	1.6	2.3	2.2	12.7	2.7	0.8
50	100	1.0	55.0	24.3	0.8	1.4	2.3	2.1	10.6	2.1	0.6
100	150	1.0	50.0	23.3	0.7	1.4	2.0	2.3	10.7	2.7	0.8

Depth, cm		Water-Holding Capacity, % (Dry Sample Wt. Basis)		Particle-Size Analysis, Wt. %			
From	To	1/3 Bar Suction	15 Bar Suction	Sand -2.0 +0.05 mm	Silt -0.05 +0.002 mm	Clay -0.002 mm	Textural Class
0	10	21.6	12.1	47.0	40.7	12.3	Loam
10	50	22.6	12.2	48.2	40.0	11.8	Loam
50	100	18.4	9.4	67.1	26.1	6.7	Sandy loam
100	150	19.1	8.7	60.5	32.5	7.0	Sandy loam

(1) n = 15 for the 0-10 and 10-50 cm sampling depths; n = 7 for the 50-100 cm depth; n = 3 for the 100-150 cm depth.

(2) Sample to extract ratio: 1 to 2.

(3) Conductivity for a saturation extract based on 1 to 2 ratio conductivity data and the 1/3 bar water-holding capacity.

TABLE 24

Chemical and Physical Traits of the Yamac Series(1)

Depth, cm		pH in	pH in	Soluble Salt Electrical Conductivity mmhos/cm	Soluble Salt Electrical Conductivity mmhos/cm	Sodium Water Soluble	Sodium NH_4 Acetate Soluble	Cation Exchange Capacity	Exchangeable Sodium
From	To	Water	0.01M $CaCl_2$	(2)	(3)	(milliequivalents/100 g)			Percentage
0	10	8.2	7.4	0.23	1.0	0.18	1.34	44.1	2.6
10	50	8.3	7.6	0.54	2.2	0.65	1.84	40.5	2.9
50	100	8.8	8.0	1.48	5.5	1.44	3.64	37.5	5.9
100	150	8.4	7.7	1.60	6.8	1.26	3.28	36.4	5.5

Depth, cm		Ammonium	Nitrate	Phosphorus $NaHCO_3$ Extractable	Potassium Available	Water Soluble					DTPA Extractable			
From	To	ppm	ppm	ppm	ppm	Magnesium ppm	Calcium ppm	Potassium ppm	Sulfate ppm	Boron ppm	Copper ppm	Manganese ppm	Iron ppm	Zinc ppm
0	10	10.3	2.3	13.0	603.1	4.6	24.0	9.3	109.6	0.5	1.5	40.5	104.0	1.3
10	50	8.2	1.2	11.6	375.6	10.8	43.2	5.9	258.8	0.5	1.3	29.3	91.5	1.0
50	100	7.3	1.2	12.6	385.7	22.2	104.4	8.9	504.1	0.6	1.3	32.6	142.6	1.5
100	150	7.8	18.0	10.6	352.0	38.7	113.8	10.7	546.2	0.6	1.2	23.0	91.2	1.0

Depth, cm		Molybdenum Anion Exchangeable	Organic Matter	Gypsum Requirement	Lime Requirement lb $CaCO_3$/	Total							
From	To	ppm	%	MEQ/100 g	acre	Phosphorus ppm	Arsenic ppm	Cadmium ppm	Chloride ppm	Chromium ppm	Cobalt ppm	Fluoride ppm	Mercury ppb
0	10	0.2	2.8	0.3	0	691.5	7.5	0.5	637.5	48.1	9.0	361.3	11.3
10	50	0.3	1.8	0.2	0	730.9	5.0	0.5	762.5	48.8	9.8	376.3	13.8
50	100	0.3	1.4	0.5	0	619.1	5.7	0.5	828.6	51.4	8.6	457.1	15.7
100	150	0.3	1.1	0.4	0	565.8	9.0	0.5	740.0	52.0	9.4	418.0	12.0

Depth, cm		Total		Selenium Available	NH_4 Acetate Extractable		Background Radioactivity				
From	To	Antimony ppm	Vanadium ppm	ppb	Nickel ppm	Lead ppm	Uranium ppm	Equivalent Uranium ppm	Equivalent Thorium ppm	Potassium Radioactivity %	Radium226 Picocuries/g
0	10	1.0	61.3	10.0	0.8	1.0	2.1	2.4	10.9	2.9	0.9
10	50	1.0	61.9	12.5	0.9	1.2	2.1	2.3	12.1	2.5	0.7
50	100	1.0	61.4	18.6	0.9	1.0	2.1	2.7	10.3	2.4	1.0
100	150	1.0	60.0	14.0	0.9	1.0	2.2	2.2	11.2	2.2	0.6

Depth, cm		Water-Holding Capacity, % (Dry Sample Wt. Basis)		Particle-Size Analysis, Wt. %			
From	To	1/3 Bar Suction	15 Bar Suction	Sand -2.0 +0.05 mm	Silt -0.05 +0.002 mm	Clay -0.002 mm	Textural Class
0	10	23.4	11.2	36.5	47.6	15.9	Loam
10	50	24.4	10.9	41.0	43.4	15.6	Loam
50	100	25.9	12.3	39.4	42.5	18.1	Loam
100	150	23.6	9.9	45.4	38.8	15.8	Loam

(1) n = 8 for the 0-10 and 10-50 cm sampling depths; n = 7 for the 50-100 cm depth; n = 5 for the 100-150 cm depth.
(2) Sample to extract ratio: 1 to 2.
(3) Conductivity for a saturation extract based on 1 to 2 ratio conductivity data and the 1/3 bar water-holding capacity.

TABLE 25

Chemical and Physical Traits of the Rivra Series(1)

Depth, cm From	Depth, cm To	pH in Water	pH in 0.01M $CaCl_2$	Soluble Salt Electrical Conductivity mmhos/cm (2)	Soluble Salt Electrical Conductivity mmhos/cm (3)	Sodium Water Soluble (milliequivalents/100 g)	Sodium NH_4 Acetate Soluble (milliequivalents/100 g)	Cation Exchange Capacity (milliequivalents/100 g)	Exchangeable Sodium Percentage
0	10	8.5	7.7	0.27	1.6	0.42	1.30	32.6	2.7
10	50	8.8	8.0	0.27	2.0	0.54	1.94	22.1	6.2
50	100	8.8	8.0	0.39	2.8	0.61	2.71	22.3	9.6
100	150	8.7	8.0	0.63	4.5	0.94	3.18	21.9	10.3

						Water Soluble					DTPA Extractable			
Depth, cm From	Depth, cm To	Ammonium ppm	Nitrate ppm	Phosphorus $NaHCO_3$ Extractable ppm	Potassium Available ppm	Magnesium ppm	Calcium ppm	Potassium ppm	Sulfate ppm	Boron ppm	Copper ppm	Manganese ppm	Iron ppm	Zinc ppm
0	10	5.6	2.8	14.3	408.3	3.7	24.1	9.3	108.0	0.6	0.7	28.0	84.0	1.4
10	50	3.4	1.3	6.0	188.3	10.7	31.7	11.7	185.3	0.6	0.6	15.0	68.7	1.3
50	100	5.3	0.7	7.0	240.0	50.0	21.3	5.4	416.0	0.6	0.8	17.7	80.7	1.5
100	150	5.1	3.6	9.7	188.3	4.1	24.4	5.6	301.0	0.6	0.8	18.0	89.3	1.2

						Total							
Depth, cm From	Depth, cm To	Molybdenum Anion Exchangeable ppm	Organic Matter %	Gypsum Requirement MEQ/100 g	Lime Requirement lb $CaCO_3$/acre	Phosphorus ppm	Arsenic ppm	Cadmium ppm	Chloride ppm	Chromium ppm	Cobalt ppm	Fluoride ppm	Mercury ppb
0	10	0.2	2.0	0.2	0	503.3	5.0	0.5	1000.0	51.7	8.0	396.7	15.0
10	50	0.1	0.7	0.3	0	532.7	6.7	0.5	1300.0	53.3	8.3	390.0	11.7
50	100	0.2	0.7	0.2	0	455.0	5.0	0.5	900.0	53.3	8.0	386.7	15.0
100	150	0.2	0.7	0.3	0	441.0	6.7	0.5	1066.7	50.0	6.7	393.3	15.0

		Total			NH_4 Acetate Extractable		Background Radioactivity				
Depth, cm From	Depth, cm To	Antimony ppm	Vanadium ppm	Selenium Available ppb	Nickel ppm	Lead ppm	Uranium ppm	Equivalent Uranium ppm	Equivalent Thorium ppm	Potassium Radioactivity %	$Radium^{226}$ Picocuries/g
0	10	1.0	53.3	13.3	0.6	1.2	2.0	2.0	1.2	2.7	0.8
10	50	1.0	46.7	13.3	0.7	1.2	2.0	1.3	1.3	2.0	0.5
50	100	1.0	55.0	13.3	0.7	1.2	2.3	2.7	1.1	2.8	0.8
100	150	1.0	51.7	16.7	0.6	1.2	2.0	2.3	1.4	2.7	0.7

		Water-Holding Capacity, % (Dry Sample Wt. Basis)		Particle-Size Analysis, Wt. %			
Depth, cm From	Depth, cm To	1/3 Bar Suction	15 Bar Suction	Sand -2.0 +0.05 mm	Silt -0.05 +0.002 mm	Clay -0.002 mm	Textural Class
0	10	16.7	8.7	62.3	30.5	7.2	Sandy loam
10	50	14.0	9.1	70.3	24.7	5.0	Sandy loam
50	100	14.4	7.2	70.8	23.8	5.4	Sandy loam
100	150	13.9	7.5	71.0	23.7	5.3	Sandy loam

(1) n = 3 for all sampling depths.

(2) Sample to extract ratio: 1 to 2.

(3) Conductivity for a saturation extract based on 1 to 2 ratio conductivity data and the 1/3 bar water-holding capacity.

TABLE 26

Chemical and Physical Traits of the Torriorthent Series[1]

Depth, cm From	Depth, cm To	pH in Water	pH in 0.01M $CaCl_2$	Soluble Salt Electrical Conductivity mmhos/cm (2)	Soluble Salt Electrical Conductivity mmhos/cm (3)	Sodium Water Soluble (milliequivalents/100 g)	Sodium NH_4 Acetate Soluble (milliequivalents/100 g)	Cation Exchange Capacity (milliequivalents/100 g)	Exchangeable Sodium Percentage
0	10	8.5	8.1	2.0	8.1	3.0	5.5	23.9	10.5
10	50	8.2	8.1	2.5	9.8	3.3	5.4	26.8	7.8

						Water Soluble					DTPA Extractable			
Depth, cm From	Depth, cm To	Ammonium ppm	Nitrate ppm	Phosphorus $NaHCO_3$ Extractable ppm	Potassium Available ppm	Magnesium ppm	Calcium ppm	Potassium ppm	Sulfate ppm	Boron ppm	Copper ppm	Manganese ppm	Iron ppm	Zinc ppm
0	10	14.4	12.0	10.3	166.4	13.8	105.7	8.6	873.6	0.7	2.9	23.4	68.3	1.2
10	50	7.4	8.5	4.3	135.7	50.2	345.0	9.0	1618.4	0.7	3.3	18.1	84.3	1.3

						Total							
Depth, cm From	Depth, cm To	Molybdenum Anion Exchangeable ppm	Organic Matter %	Gypsum Requirement MEQ/100 g	Lime Requirement lb $CaCO_3$/acre	Phosphorus ppm	Arsenic ppm	Cadmium ppm	Chloride ppm	Chromium ppm	Cobalt ppm	Fluoride ppm	Mercury ppb
0	10	0.4	2.0	0.5	0	510.4	12.1	0.5	1014.3	36.4	6.7	642.9	30.7
10	50	0.5	2.0	0.4	0	399.9	16.4	0.5	1242.9	36.4	7.7	645.7	37.1

		Total			NH_4 Acetate Extractable		Background Radioactivity				
Depth, cm From	Depth, cm To	Antimony ppm	Vanadium ppm	Selenium Available ppb	Nickel ppm	Lead ppm	Uranium ppm	Equivalent Uranium ppm	Equivalent Thorium ppm	Potassium Radioactivity %	Radium226 Picocuries/g
0	10	1.0	61.4	55.7	1.1	1.9	2.1	2.4	8.6	2.6	0.8
10	50	1.0	66.4	85.7	1.6	2.6	2.3	2.7	7.4	2.1	0.9

		Water-Holding Capacity, % (Dry Sample Wt. Basis)		Particle-Size Analysis, Wt. %			
Depth, cm From	Depth, cm To	1/3 Bar Suction	15 Bar Suction	Sand -2.0 +0.05 mm	Silt -0.05 +0.002 mm	Clay -0.002 mm	Textural Class
0	10	24.8	10.3	27.1	60.6	12.2	Silt loam
10	50	25.4	11.9	34.4	56.4	9.3	Silt loam

(1) n = 8 for both sampling depths.
(2) Sample to extract ratio: 1 to 2.
(3) Conductivity for a saturation extract based on 1 to 2 ratio conductivity data and the 1/3 bar water-holding capacity.

available phosphorus appears adequate, but the soil should be periodically tested to determine the phosphorus status. If the level falls below 10 ppm, phosphorus fertilizer should be applied to the soil. Other macro- and micronutrients occur in adequate to ample concentrations to support normal plant growth.

Evaluation of Processed Oil Shale As a Medium for Plant Growth

Samples of TOSCO processed oil shale from Marathon's Portland shale claim approximately 3 miles northwest of Tract C-a were supplied by the RBOSP and were analyzed in the same manner as the soil samples. The purpose of this investigation was to establish preliminary information concerning the chemical and the physical properties of processed oil shale and how these properties might influence plant growth when the processed shale is used as a subsoil. Results of this study are presented in Table 27. Following is a discussion of how these parameters may affect plant growth.

pH

Processed oil shale from a variety of sources shows a wide range in pH. Retorting temperatures, sodium carbonate content of the oil shale, and the amount of time the spent shale has been exposed to air are important variables influencing pH (Cook, 1974). The RBOSP processed shale had a pH of 8.5 in water, a level considered strongly alkaline, but not necessarily detrimental to plant growth.

TABLE 27

Chemical and Physical Properties of Processed Oil Shale[1]

pH in Water	pH in 0.01M $CaCl_2$	Soluble Salt Electrical Conductivity mmhos/cm (2)	Soluble Salt Electrical Conductivity mmhos/cm (3)	Sodium Water Soluble (milliequivalents/100 g)	Sodium NH_4 Acetate Soluble (milliequivalents/100 g)	Cation Exchange Capacity (milliequivalents/100 g)	Exchangeable Sodium Percentage
8.5	8.3	4.80	16.5	1.62	4.88	13.0	25.1

				Water Soluble					DTPA Extractable			
Ammonium ppm	Nitrate ppm	Phosphorus $NaHCO_3$ Extractable ppm	Potassium Available ppm	Magnesium ppm	Calcium ppm	Potassium ppm	Sulfate ppm	Boron ppm	Copper ppm	Manganese ppm	Iron ppm	Zinc ppm
15.5	0.6	11.8	206.3	152.9	501.3	15.2	15,384	1.1	3.4	7.1	130.0	9.2

				Total							
Molybdenum Anion Exchangeable ppm	Organic Matter %	Gypsum Requirement MEQ/100 g	Lime Requirement lb $CaCO_3$/acre	Phosphorus ppm	Arsenic ppm	Cadmium ppm	Chloride ppm	Chromium ppm	Cobalt ppm	Fluoride ppm	Mercury ppb
11.4	9.4	<0.2	0	838.4	32.5	<0.5	862.5	35.0	10.0	1485.0	124.0

Total			NH_4 Acetate Extractable		Background Radioactivity				
Antimony ppm	Vanadium ppm	Selenium Available ppb	Nickel ppm	Lead ppm	Uranium ppm	Equivalent Uranium ppm	Equivalent Thorium ppm	Potassium Radioactivity %	Radium226 Picocuries/g
2.0	120.0	17.5	1.1	1.0	6.8	5.2	5.6	1.6	1.5

Water-Holding Capacity, % (Dry Sample Wt. Basis)				Particle-Size Analysis, Wt. %			
1/10 Bar Suction	1/3 Bar Suction	1 Bar Suction	15 Bar Suction	Sand -2.0 +0.05 mm	Silt -0.05 +0.002 mm	Clay -0.002 mm	Textural Class
32.3	29.0	17.5	5.7	49.6	44.1	6.3	Sandy loam

(1) Analyses were replicated eight times.

(2) Sample to extract ratio: 1 to 2.

(3) Conductivity for a saturation extract based on 1 to 2 ratio conductivity data and the 1/3 bar water-holding capacity.

Soluble Salt Electrical Conductivity

The RBOSP processed shale is highly saline and this trait would severely restrict the growth of most plant species. However, some grasses including Nuttall alkali-grass and saltgrass and some shrubs (greasewood, fourwing saltbush, and others) would be unaffected or only slightly affected by the salinity in this processed oil shale. The application of nonsaline topsoil to the spent shale surface could mitigate the detrimental effects of salinity on plant growth. As previously discussed, highly saline material was found in the study area at depths greater than 50 cm. Plant growth appeared unaffected. This suggests that the saline nature of the spent shale would not significantly restrict plant growth if at least 50 cm of nonsaline topsoil is applied to the shale. However, salinization of the topsoil can occur. Harbert and Berg (1974) leached TOSCO spent shale and applied 15 cm of topsoil to the shale. The spent shale averaged 15 mmhos/cm in electrical conductivity. At the end of a four-month period, the electrical conductivity of the topsoil increased from 3 to over 10 mmhos/cm. Both the shale and the soil were of similar texture and salts contaminated the topsoil by the process of capillary rise. No salinization occurred in the topsoil when 30 cm of topsoil was applied to unleached processed oil shale. Apparently, sufficient water was not present for capillary movement. When U. S. Bureau of Mines (USBM) processed oil shale was used (electrical conductivity of 10 mmhos/cm), salinization of the topsoil did not occur. This was at least partially due to the coarse texture of the USBM processed shale and this apparently formed

a barrier to the upward capillary movement. Thus, the application of nonsaline topsoil to RBOSP processed oil shale may or may not alleviate salinity problems.

Exchangeable Sodium Percentage

The RBOSP processed shale had an ESP of 25.1 and consequently, water penetration and root growth into this shale will be restricted. However, the degree of restriction is lessened because this shale contains only 6.3% clay. Sodic material was found in the Tract C-a study area and when this material was deeper than 50 cm below the surface, plant growth appeared unaffected. Thus, if at least 50 cm of nonsodic topsoil is applied to the processed soil shale, ESP should not seriously restrict plant growth.

Plant Nutrients

The concentration of nitrogen and phosphorus were surprisingly high for processed oil shale. However, the nitrogen in the ammonium may not be readily available for plant uptake (Berg 1973). Ample amounts of available potassium, water-soluble macronutrients, and micronutrients were found in the spent shale. The analyses indicate that fertilization of processed oil shale would not be necessary if sufficient topsoil is applied.

The concentration of sulfate in the spent shale is extremely high, but any direct toxicity due to the sulfate ion is not expected.

Relatively high amounts of exchangeable molybdenum were found in the RBOSP processed oil shale. While these high concentrations of molybdenum are unlikely to restrict plant growth, plants growing on revegetated spent shale

may absorb sufficient molybdenum to poison livestock, especially cattle. Harbert and Berg (1974) found that the vegetation growing on spent TOSCO shale contained relatively high amounts of molybdenum. The high sulfate content of the RBOSP processed shale should substantially decrease the plant absorption of molybdenum. As a precaution, before revegetated areas are opened to grazing, the forage should be analyzed for its molybdenum content. If the molybdenum is found to be greater than 5 ppm, corrective measures should be taken. These measures include:

1. Supplying cattle with a supplemental form of copper either through mouth, intravenous injections, or by spraying vegetation with a copper compound (Underwood 1971), or
2. Grazing animals other than cattle on reclaimed areas. Cattle are very intolerant of molybdenum, sheep are somewhat tolerant, and horses appear unaffected by forage containing high amounts of molybdenum (Underwood 1971), or
3. Close the revegetated area to grazing and harvest the hay. The molybdenum in hay is considerably less toxic than that in green plants (Kubota 1975).

Trace Elements

Arsenic, fluoride, mercury, antimony, and vanadium were substantially more concentrated in the processed oil shale (Table 27) than in the soils of the study area. However, the concentration of these trace elements was well within the range cited in the literature and considered normal for surface soils and nontoxic to plants and animals.

Background Radioactivity

Background radioactivity of the spent oil shale was slightly higher than that found for Tract C-a and adjacent areas, although this radioactivity is still within the range considered nonsignificant to living organisms. Deviations from radiological equilibrium are evident, but appear to be of no ecological consequence.

Physical Properties

This processed oil shale has the potential to retain sufficient water for normal plant growth, although the ESP may restrict water infiltration and percolation. The texture is a sandy loam and is typical of much of the soil in the study area.

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